NASA/CR—2000-209879

TRAP/SEE Code Users Manual for Predicting Trapped Radiation Environments

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Prepared for Marshall Space Flight Center
under Contract NAS8-40294
and sponsored by
The Space Environments and Effects Program
managed at the Marshall Space Flight Center

January 2000

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Acknowledgements

The TRAP/SEE code has been assembled as part of a NASA-funded study performed by Science Applications International Corporation (SAIC) entitled "Trapped Radiation Model Uncertainties for Spacecraft Design Applications", NASA Contract NAS8-40294, with contract administration through the NASA Space Environments and Effects (SEE) Program Office (B. Kauffman, contract coordinator) located at the Marshall Space Flight Center, Huntsville, Alabama.

The contract technical representative was J. W. Watts, Jr., NASA/MSFC Code ES84, who provided much assistance, including an initial version of the Visual Basic code interface. We thank E. J. Daly and H. D. R. Evans of the European Space Agency ESTEC facility for providing subroutines containing their extrapolation method which have been incorporated. The orbit code incorporated, called GRAV (undocumented), was developed mainly by R. Burrows and L. Mullins at NASA/MSFC; we thank L. Howell, NASA/MSFC, for providing us a PC version with special interface routines he developed and for helpful discussions. We also thank J. Barth, NASA/GSFC, for her review of this manual and numerous helpful comments.

Finally, we express appreciation to the original developers of the AP8 and AE8 trapped radiation models (J. T. Vette and colleagues at Aerospace Corp. and NASA/GSFC). While the models have shortcomings based on current knowledge, they have provided essential tools for trapped radiation environment and effects assessments for almost three decades.

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1. Overview

The TRAP/SEE code predicts proton and electron spectra in the Earth's trapped radiation belts. Code features (for version 1.1) are listed in Table 1 and summarized below.

1.1 Attributes of Code

The TRAP/SEE code contains the trapped proton and electron models for solar minimum and solar maximum developed by Vette and colleagues [1-3] and designated as AP8MIN, AP8MAX, AE8MIN, and AE8MAX. These models are incorporated essentially as originally written; fundamental changes to the original models have not been made.

The TRAP/SEE code has the following basic features:

- An orbit code is incorporated which accurately accounts for trajectory perturbations for both low-Earth orbits (LEO) and high-apogee, highly-elliptical Earth orbits (HEO).
- In addition to the standard "Vette versions" of the trapped models, "ESA versions" of the models, containing modifications made by Daly and Evans of the European Space Agency (ESA) ESTEC facility for an improved data base interpolation method [4], are also included.
- A convenient user interface for executing the code is provided using Microsoft Visual Basic software. The code operates on an IBM-compatible PC using Windows 95 or 98 operating system.

The models incorporated are described in Sec. 2. Input parameters needed to operate the code are discussed in Appendix A, and a summary of input definitions is included in the code Help files.

1.2 Output Provided

The TRAP/SEE code provides five types of output (for either electrons or protons):

- orbit-average integral and differential flux spectra

Table 1. Summary of TRAP/SEE version 1.1 code features.

❑ Attributes

- Treats HEO and LEO orbits
- Allows both conventional and ESA methods for data base interpolation
- Convenient user interface
- Fast operation on PC platform

❑ Models, Methods, and Software

- Trapped Radiation Models: AP8MIN, AP8MAX, AE8MIN, AE8MAX
- Data Base Interpolation: Vette and ESA methods
- Magnetic Field Calculations: GSFC ALLMAG, GDALMG, and LINTRA codes
- Magnetic Field Models:
  Solar Minimum: 80-term IGRF 1965.0 model, projected to 1964
  Solar Maximum: 168-term USCGS model for 1970
- Magnetic Moment: calculated from field models
- Orbit Calculations: MSFC GRAV code
- User Interface Software: Microsoft Visual Basic (v. 6.0)
- Operational Platform: IBM-compatible PC, Windows 95/98

❑ Output Provided

- Orbit average trapped proton and electron energy spectra at solar min or solar max
- Peak flux per orbit and orbit fluence (optional)
- Spectra at specified points along orbit (optional)
- Variable values at each time step along trajectory (optional)
- Orbit parameters (optional)

- peak flux encountered during an orbit and fluence per orbit (optional output)
- differential and integral flux spectra at specified points along an orbit (optional output)
- an output file containing various variable values on a point-by-point basis -- i.e., at each time step along the orbit where the flux is non-zero (optional output)
- an output file of orbit parameters at each time step along orbit (optional output)

Thus, output is provided for both orbit-average spectra (needed, for example, in computing orbit-average mission dose) and for the peak spectra and spectra at points along an orbit (needed, for example, in computing worse-case and nominal single event effect rates).

Detailed descriptions of the output and an example calculation are given in Appendices B and D, respectively. Default values used by the code which can be changed by the user are described in Appendix C. Outputs for typical types of applications are discussed in Appendix E.

1.3 Model Limitations and Prediction Uncertainties

Fundamental model limitations and TRAP/SEE code application restrictions are discussed in Sec. 3. As part of the present study under the SEE Program, AP8 and AE8 model predictions have been compared with various sets of flight data to obtain quantitative estimates of model prediction uncertainties. A synopsis of these results is given in Sec. 4; details are available as separate reports [5, 6].

Predictions using the AP8 and AE8 models can vary depending on the details of how the models are implemented and operated. Some of the implementation factors which can influence the trapped model predictions are summarized in Sec. 5.

2. Models and Codes Incorporated

2.1 Calculational Steps

The calculational procedure consists of four main steps:

- Orbit code calculation -- provides the latitude, longitude, and altitude at time steps along the trajectory
- Magnetic field calculation -- uses orbit code output to calculate the magnetic field intensity (B), the minimum intensity along the field line (B_o), and the McIlwain L parameter at each time step
- Trapped flux calculation -- extracts at each time step the integral flux spectrum from the appropriate data base (proton or electron, solar minimum or maximum) of fluxes stored at discrete energy, B/B_o, and L values, and performs interpolation for the B and L of the time step
- Output calculation – differential energy spectrum calculation and summations, normalizations, etc. needed in generating output files

A summary of the models and codes used for these calculations follows.

2.2 Orbit Code

The GRAV code, developed and extensively applied at MSFC, is used for orbit calculations. This orbit code takes into account perturbations to the orbital elements by nonspherical gravitational terms due to the Earth's oblateness and the influence of gravitational forces by the Moon and Sun. In addition, options are provided to include atmospheric drag (in the 200 to 1000 km altitude range, using the 1976 U.S. standard atmospheric model) for low-Earth orbits and the influence of solar radiation pressure for high-apogee orbits.

2.3 Magnetic Field Models

The following magnetic field models are used, which correspond to the fields at the time the flight data incorporated in the flux data bases were taken: for solar minimum, 80-term International Geomagnetic Reference Field for 1965.0 [7] projected to 1964; for solar maximum, U.S. Coast and Geodetic Survey 168-term geomagnetic field model for 1970 [8]. The magnetic moment, needed in determining B_o, is calculated from the magnetic field models (as opposed to using a fixed value, which is the procedure used in some implementations of the models, including the models as originally issued). Considerations in determining appropriate field models and in specifying the magnetic moment are discussed in Sections 5.3 and 5.4, respectively.

The B and L calculations are performed using the ALLMAG code and associated programs developed by Stassinopoulos and Mead [9].

2.4 Trapped Radiation Models

Incorporated are the standard "Vette versions" of trapped proton and trapped electron models for solar minimum and solar maximum conditions and ESA versions of the these models, which contain an improved data base interpolation method for low altitudes as described in Sec. 5.5. The particular implementation of the Vette codes incorporated here is that currently in common use at NASA/MSFC.

2.5 Output Calculations

The TRAP/SEE code uses the basic output from the trapped radiation data bases (integral flux values for each energy grid value at each time step along the orbit) to calculate output fluxes in several forms (orbit average values, peak flux per orbit, etc.), as discussed in detail in Appendix B. The integral fluxes are extracted from the data bases at constant time steps (specified as input) along the orbit. The differential flux at a given energy is calculated by differentiating a three-point fit to the integral flux about the energy. The procedure for changing the spectra energy grid values is discussed in Appendix C.

3. Model Limitations

Major limitations of the AP8 and AE8 models and, therefore, restrictions for TRAP/SEE code applications, are summarized below.

3.1 Solar Cycle Dependence

The models provide fluxes at or near solar minimum or solar maximum conditions only, not the variations which occur during a solar cycle. (For an indication of the trapped proton solar cycle dependence at low altitudes, see recent publications of measurements made on the NOAA spacecraft at 800 km over 1.5 solar cycles [10] and long-term measurements made on the Mir Space Station at 370 – 420 km [11].)

3.2 Transients

The models are static and most accurate in providing average fluxes for time periods of about 6 months or more. In particular, the dynamics of the outer electron belt and large temporal variations in high altitude proton and electron fluxes due to geomagnetic disturbances such as those observed on the CRRES mission [12] are not accounted for.

3.3 Directionality

The models provide only omnidirectional fluxes without any angular dependence. Thus, the substantial anisotropy of trapped proton fluxes at low altitudes, as observed for example by radiation effects measurements on the LDEF satellite [13, 14], are not taken into account.

Models for generating directional trapped proton spectra from the AP8 omnidirectional spectra have been developed (e.g., [15, 16]) and have been applied, for example, to generate a calculational data base of orbit-average directional trapped proton spectra for orbits below 500 km [17].

3.4 Energy Extrapolation

While the AP8 and AE8 models as implemented here output flux spectra in the energy range 50 keV to 600 MeV for protons and 40 keV to 7.5 MeV for electrons, it is important to note that the lowest and highest energy regions represent energy extrapolations of data base values and not actual measurement data. For example, according to Vampola [18], AE8 is not based on reliable data for energies above about 2 MeV in the outer electron zone. Also, the low-energy proton spectra from AP8 are uncertain below about 10 MeV, so the application of AP8 fluxes in assessing near-surface effects where energies ~ 100 keV are important is not advised. (An alternative in this case is to use low-energy proton spectra measured on the S3-3 satellite, which provides spectra down to 80 keV for altitudes below 8200 km [19]).

3.5 SAA Drift

Because of secular geomagnetic changes, the high proton flux region at low altitudes, the so-called South Atlantic Anomaly (SAA), drifts westward geographically at a rate of about 0.3° per year [20]. Since the magnetic fields that must be used to retrieve fluxes from the model data bases are for epochs 1964 and 1970 for solar minimum and solar maximum, respectively, the models do not predict the correct locations of fluxes in the SAA region – i.e., the actual area of high flux is shifted westward from the predicted high-flux area. Thus, for example, if the models are used to predict the location along an orbit where high radiation backgrounds to an onboard sensor is expected, the location will be incorrect.

However, the SAA drift can be accounted for approximately by simply shifting the longitude of the model flux predictions. The point-by-point output file from a TRAP/SEE run contains several integral flux values and the geographic east longitude, ϕ, at each time step. The shift can be taken into account by considering the fluxes to be at longitude $\phi' = \phi - \Delta\phi$, where $\Delta\phi = 0.3(t - T)$, t = the date of interest in years, and T = 1964.0 for solar minimum and 1970.0 for solar maximum. Another method for predicting the SAA drift, which is probably the most accurate currently available, is to use the NOAAPRO code [10].

4. Model Uncertainties

The following is a brief summary of AP8 and AE8 model uncertainties based on recent model comparisons with flight data discussed in detail in [5] and [6].

4.1 AP8 Model – Low Altitudes

Based on AP8 model comparisons with several sets and types (flux, dose, activation) of flight data for low altitudes (below about 2000 km, where most of the flight data are available for comparison), the AP8 model underpredicts by about a factor of 2. By multiplying the AP8 model output fluxes by a factor of 2, the resulting corrected model predictions are within about ± 25% of the flight data, as illustrated in Fig. 1 for 28.5° inclination orbits; comparisons at 51.6° and 90° inclinations are similar [5]. This empirical factor of 2 correction applies to both AP8MIN and AP8MAX predictions and is independent of proton energy (at least for energies above about 15 MeV, the energy range where model checks against flight data have been made).

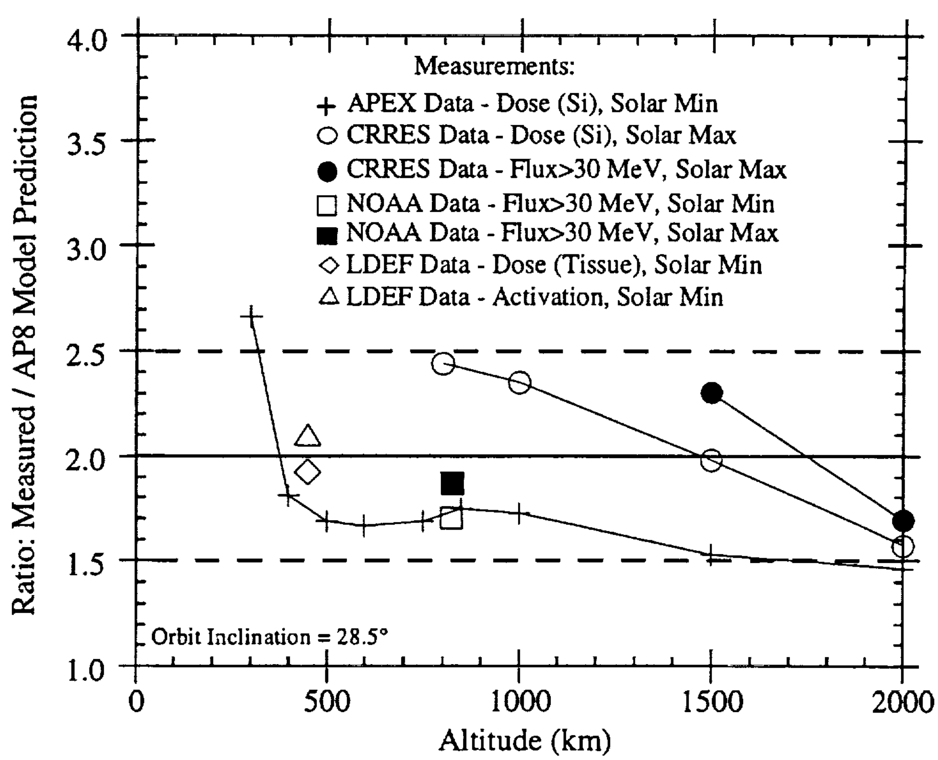

Fig. 1. Comparison of flight data with predictions using AP8 trapped proton model for circular orbits with 28.5 ° inclination, from [5].

This factor of 2 correction applies, of course, only for situations where the AP8 model is used within the limitations summarized above in Sec. 3. In particular, this correction factor is not generally applicable for short duration flights such as for the Space Shuttle, as shown in [6].

4.2 AP8 Model – High Altitudes

Fewer flight data sets are available for testing the accuracy of the AP8 model at higher (> 2000 km) altitudes. Based on proton flux and dose data taken on the CRRES mission [21, 22], AP8 continues to underestimate to altitudes just past the peak intensity of the proton belt and then overestimates in the outer regions of the belt for normal (quiet) geomagnetic conditions (e.g., Fig. 2). As indicated in Fig. 2, the CRRES data show that the outer regions of the belt are subject to large temporary enhancements during active geomagnetic conditions; the AP8 model may grossly underestimate proton fluxes in this region during, and some months after, such geomagnetic disturbances.

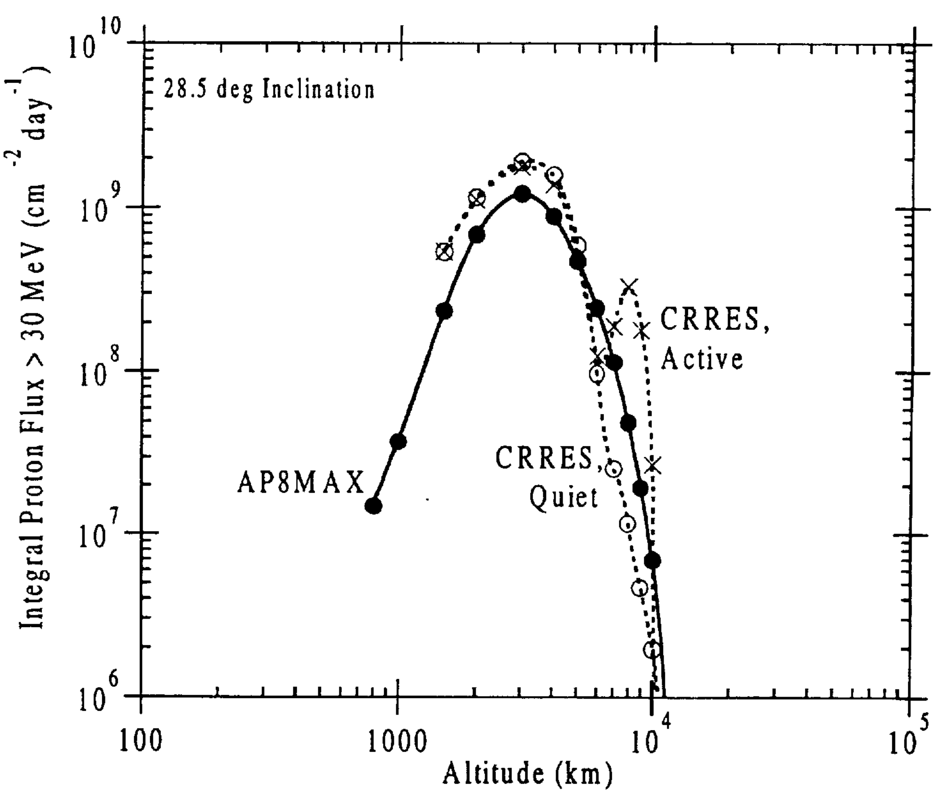

Fig. 2. Altitude dependence of proton flux > 30 MeV in inner radiation belt predicted using AP8MAX model and from measurements [21] on the CRRES satellite for quiet and active geomagnetic conditions, for circular 28.5 deg. inclination orbits (from [5]).

4.3 AE8 Model – Low Altitudes

Table 2 compares measured-to-predicted dose ratios at low altitudes (< 2000 km) based on APEX satellite measurements [23] of the dose behind thin planar shielding (aluminum, 4.29 mils thick) and the dose predicted [5] based on the AE8MIN trapped electron model and shielding calculations using the SHIELDOSE2 code. These measurements were made during solar minimum and normal (quiet) geomagnetic conditions. The comparisons are in terms of orbit-average doses for circular orbits.

Table 2. Measured-to-predicted electron dose ratio at low altitudes based on APEX satellite data [23] and AE8MIN trapped electron model, from [5].

Inclination (deg)	Altitude km)	Exposure Region	Measured/AE8MIN Model
< 40	< 750	"under belts" (low flux)	2-10 (or more), highly variable
< 40	750 - 2000	inner belt, inner edge	2 - 10
> 40	300 - 750	polar horns (outer belt)	0.5 - 1.5
> 40	750 - 2000	inner belt, inner edge	1 - 2

The ratios in Table 2 can be considered in four regimes: (a) For inclinations below about 40° and altitudes below about 750 km, the orbits are essentially below the radiation belts, and the dose levels are low. Thus, while AP8MIN underprediction can be large in this region, the practical importance is lessened because of the low electron intensity and dose levels. (b) For inclinations below 40° and orbits through the inner edge of the inner belt (750 – 2000 km), the predicted dose using AE8MIN is higher than measured by a factor of 2 to 10, with the largest differences at the lowest inclinations and altitudes. (c) For low altitudes (below about 750 km) and high inclinations (above about 40°), the dose is due mainly to exposure in the "horns" of the outer zone electrons which reach low altitudes at high latitudes. In this region, the predicted and measured doses for normal activity agree within about ± 50%. However, the dose in this region is sensitive to outer zone intensity fluctuations caused by magnetic disturbances, so the model uncertainty depends on the magnetic activity level, as shown in [5]. (c) For altitudes in the 750 – 2000 altitude range and high (> 40°) inclinations, the dose is due to electrons in the inner edge of the inner radiation belt, and AE8MIN overpredicts the dose by about a factor of 1 to 2.

4.4 AE8 Model – High Altitudes

Figure 3 compares dose predictions based on AE8MAX trapped electron predictions with measured doses based on CRRES satellite measurements [22] for 0.57 g/cm^2 shielding. Here the orbit-average dose is compared for circular orbits at 28.5° inclination vs. altitude. The CRRES data are shown for low magnetic activity conditions and for average dose measurements during the 6-month observation period following the large March 1991 geomagnetic storm and solar event injection ("CRRES, High Activity" curve).

For the low activity conditions, Fig. 3 shows: (a) in the peak and outer edge of the inner belt (≈ 2,000 – 5,000 km), AE8MAX overpredicts by about a factor of three, (b) in the low dose 'slot' region between the inner and outer belts (5,000 – 10,000 km), AE8MAX overpredicts by as much as a factor of 50, (c) in the peak region of the outer belt, AE8MAX overpredicts by a factor of 5 – 10, and (d) in the outer regions of the outer belt, AE8MAX overpredicts by a factor of 10 – 100.

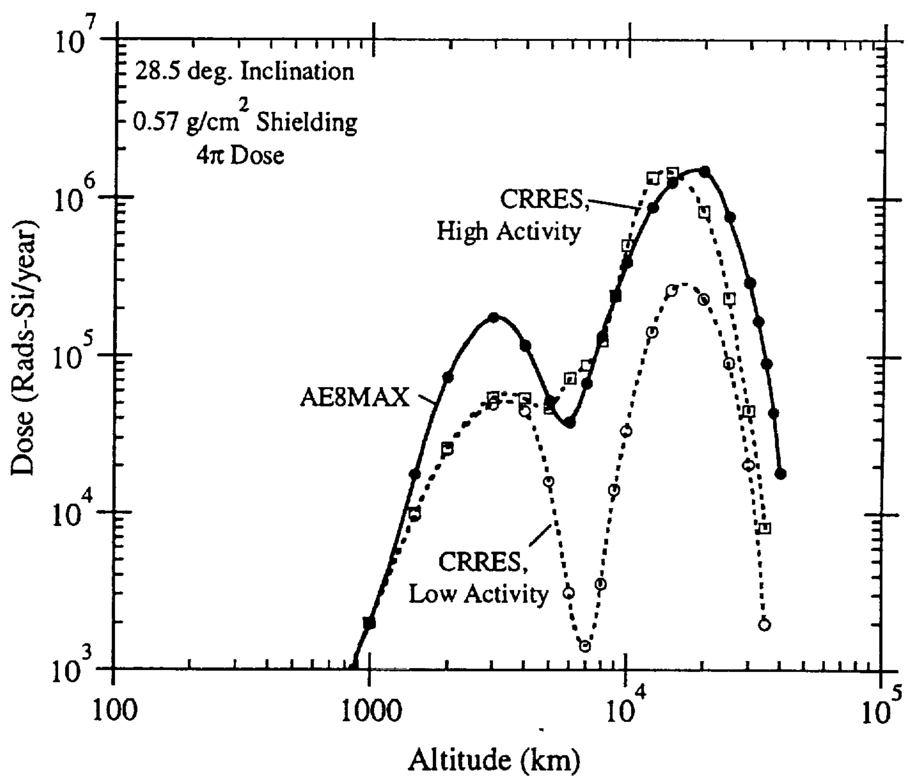

Fig. 3. Comparison of electron dose based on CRRES satellite measurements for low and high magnetic activity conditions [22] with predictions using AE8MAX model, from [5].

During periods of high activity, Fig. 3 shows that the electron dose is enhanced down to altitudes corresponding to the peak of the inner belt, with increases of about two orders-of-magnitude in the slot region and one order-of-magnitude in the peak region of the outer belt. However, the static AE8MAX model overestimates the dose levels for quiet conditions by such a large amount that the model results are not appreciably exceeded during these extremely high activity conditions, and the model doses are still overestimates in the inner belt (by a factor of about 3 near the peak) and for the outer edge of the outer belt (by a factor of about 10 or more).

Data from the CRRES mission taken after the extremely large geomagnetic disturbance and solar particle event of March 1991 provide what is probably a practical upper limit for temporal enhancements to the trapped electron populations. Thus, comparison of these data with AE8, which is a static model and does not account for fluctuations due to geomagnetic storms, provides a bound on AE8 uncertainty related to geomagnetic activity.

5. Factors Which Can Influence Predictions

The AP8 and AE8 models have been implemented as software packages and applied for trapped radiation predictions at various facilities worldwide for several decades. While there have not been fundamental changes to the data bases and basic models since they were issued (in 1976 for AP8, in 1983 for AE8), differences in implementation (such as coupling with different orbit codes), input parameter selections, and details of operation can result in the same models providing somewhat different results. We summarize below some of these factors which can influence predictions and indicate the assumptions used in implementing the TRAP/SEE code. While some of these factors are rather subtle, together they can account for the substantial difference in predicted fluxes sometimes observed from the codes used at different facilities.

5.1 Orbit Code Fidelity

In coupling the AP8 and AE8 models with an orbit code to obtain orbit-average spectra, it is essential for high-apogee, highly-elliptical Earth orbits (HEO) that perturbations due to the gravitational pull of the moon and sun be taken into account. For example, Fig. 4 shows the change in inclination and perigee with time for a spacecraft with 28.5° inclination, 10,000 km perigee, and 140,000 km perigee at insertion (orbit parameters for the Chandra x-ray astronomy satellite). For this example, perigee changes from 10,000 to about 30,000 km and inclination from 28.5° to about 50° over a 5-year mission, so the locations of trajectory passes through the radiation belts change greatly during the mission.

Another orbit code feature which can influence trapped radiation predictions is treatment of the earth's oblateness. Orbit codes calculate the geocentric radius at time steps along the trajectory, and the radius of the earth is subtracted to obtain altitude, $h = R - R_E$. The altitude is used to calculate the magnetic field at the time step, which in turn is used to extract fluxes from the AP8 and AE8 data bases. R_E varies with latitude and time step due to the equatorial bulge of the Earth, but some orbit codes use a fixed value (either mean or equatorial radius). While the R_E variation is relatively small (21 km difference between poles and equator [24]), neglecting the Earth's oblateness can cause appreciable flux errors near the low-altitude edge of the proton belt where gradients are steep.

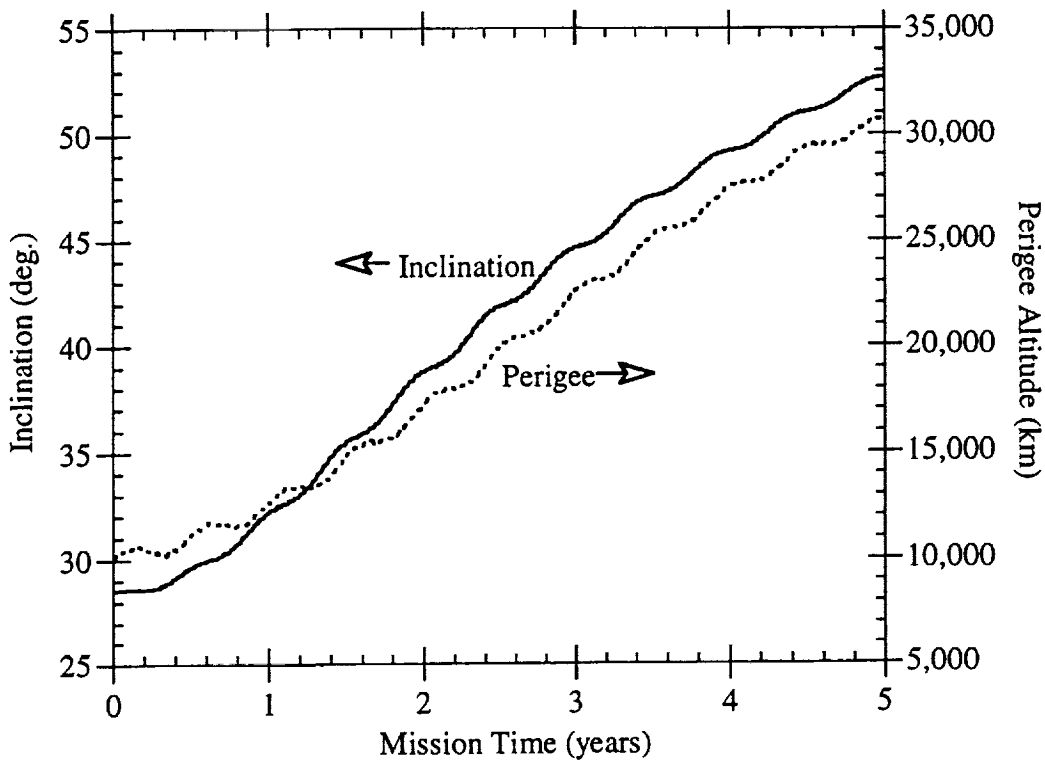

Fig. 4. Example orbit element perturbations for a highly elliptical orbit (orbit parameters at insertion: i=28.5°, h_p=10,000 km, h_a=140,000 km, Arg. Perigee = 270°, RAAN = 200°).

The orbit code routines incorporated in the TRAP/SEE code take into account orbit element perturbations due to gravitational forces from the moon and sun (as well as the capability for treating atmospheric drag and solar radiation pressure perturbations) and include the effect of the earth's oblateness in computing altitudes.

5.2 Input Values for Convergence

Mission average spectra are determined by computing flux values during short time steps ("sampling time") around the orbit for a specified total orbit time (or, equivalently, for a total number of orbits), and then dividing the accumulated products of flux times sampling time by the accumulated time. Generally, the orbit time specified for the calculation is much less than the actual mission time in order to save computation time. Since the flux variation around an orbit, and variations from orbit to orbit, can be large, especially for orbits passing through the South Atlantic Anomaly region, the code user needs to specify input values for the sampling time and number of orbits so that adequate flux convergence is obtained. Guidelines for specifying input values for the number of orbits and sampling times needed to achieve convergence are discussed below.

Low-Earth Orbits

Figure 5 illustrates the convergence of trapped electron and proton fluxes as calculated by the TRAP/SEE code for a circular 500 km, 51.6° inclination orbit and one minute sampling time. Plotted are the normalized running total values; i.e., after a given number of orbits, the accumulated electron or proton fluence is divided by the accumulated time, and then divided by the electron or proton flux for the maximum number of orbits considered (80 in this case) to show fractional variations. This shows that LEO orbit convergence is obtained for a code run time corresponding to about 80 orbits. Figure 6 illustrates that this conclusion is independent of inclination. For higher altitude orbits with trajectories through the 'heart' of the belts rather than through the SAA, quicker convergence is obtained, as illustrated by Fig. 7 for protons and Fig. 8 for electrons.

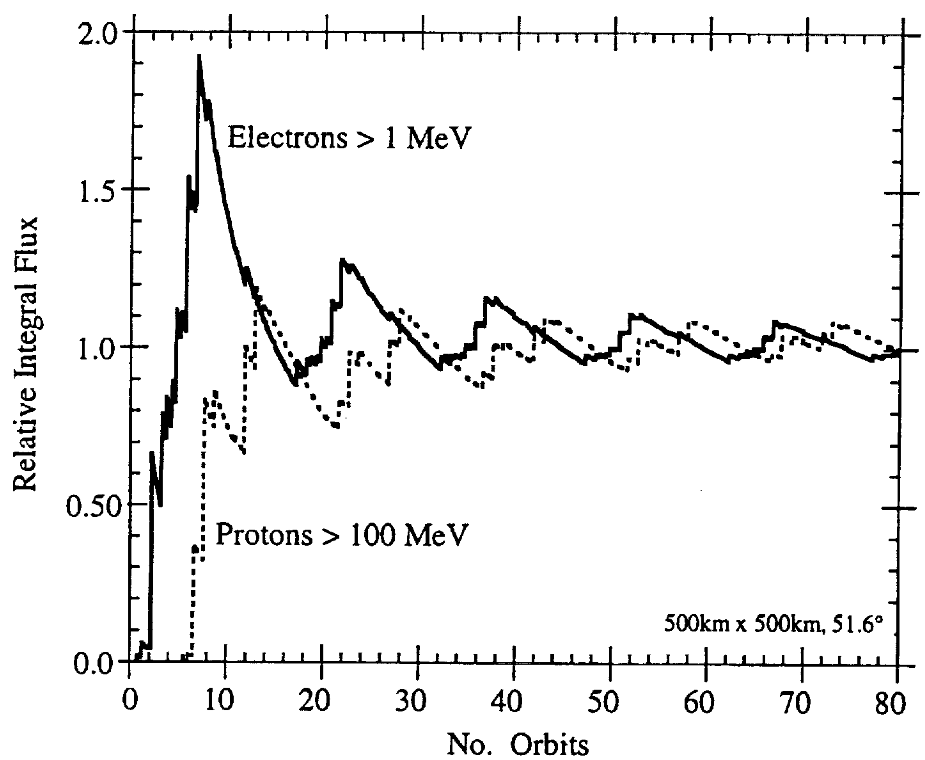

Fig. 5. Example of number of orbits needed for flux convergence for LEO orbits (TRAP/SEE code calculation for circular 500 km, 51.6° orbit).

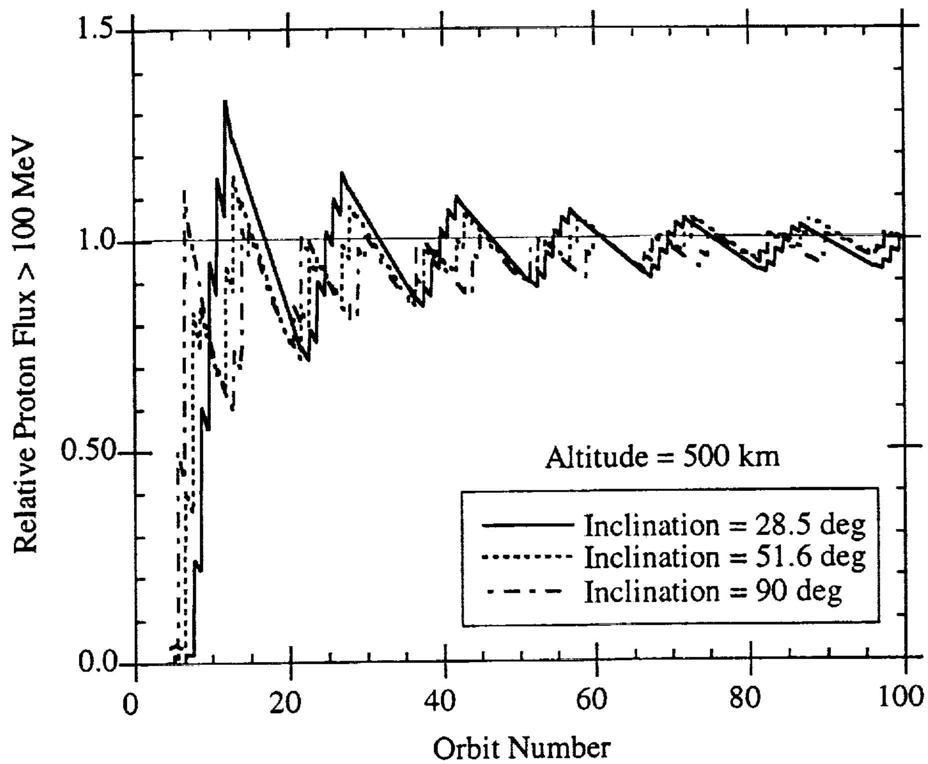

Fig. 6. Example of proton flux convergence for circular 500 km orbits at different inclinations.

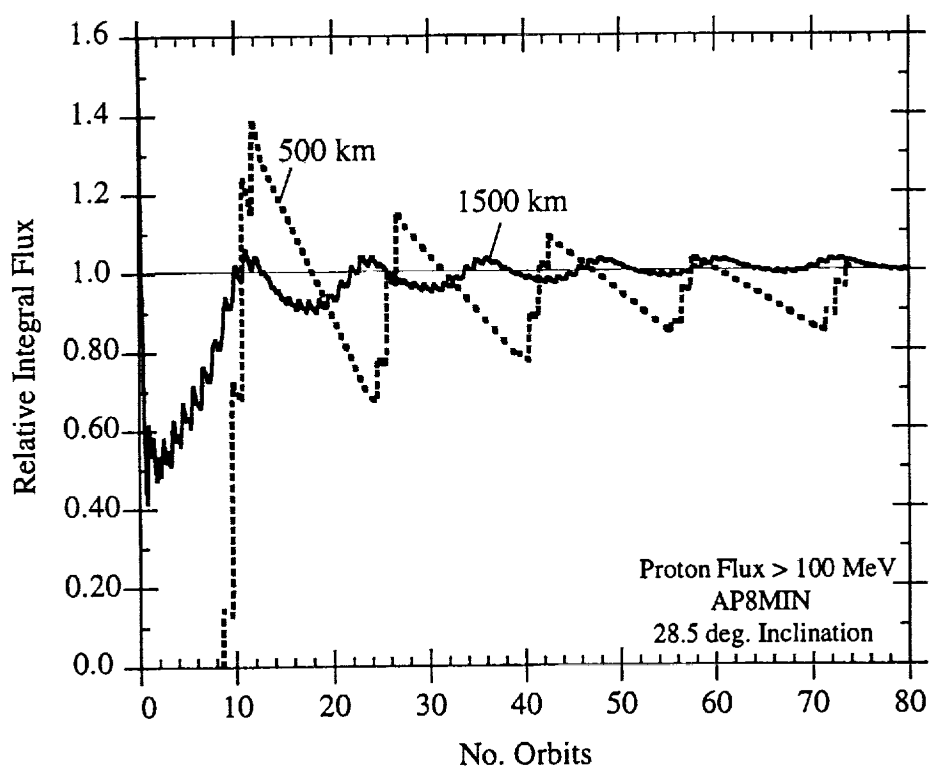

Fig. 7. Trapped proton convergence for low-altitude orbit through South Atlantic Anomaly (example at 500 km) and for orbit in "heart" of proton belt (example at 1500 km), for circular orbits at 28.5 deg. inclination.

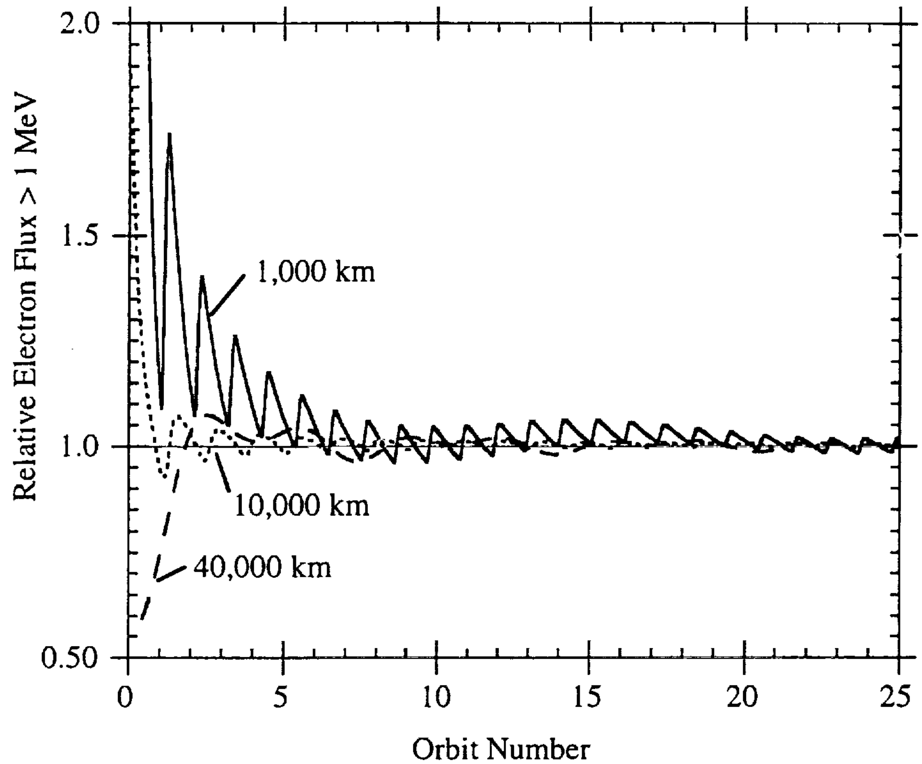

Fig. 8. Trapped electron convergence for example circular orbits at different altitudes, 0° inclination.

Sampling Time

Specifying an appropriate sampling time input value for the calculation is basically a trade between choosing sufficiently small intervals that flux variations around the orbit are properly accounted for versus making the time intervals so small that the required computer time for the calculation becomes unreasonably long. Generally, about one minute sample times for low altitudes and 10 min. for high altitudes are adequate choices for LEO orbits. The sampling time vs. altitude curve of Fig. 9, which was generated by keeping the number of time steps per orbit approximately the same as altitude changes, can be used as a general guide for circular orbits.

HEO Orbits

As indicated above, orbit parameters for highly ellipical orbits can change significantly with on-orbit time, so flux values do not converge in the same sense as with LEO orbits. Thus, the most accurate way of treating HEO orbits is to run the calculation for the actual number of orbits corresponding to the mission time of interest. With TRAP/SEE this can be done with reasonably short computation times, as discussed below.

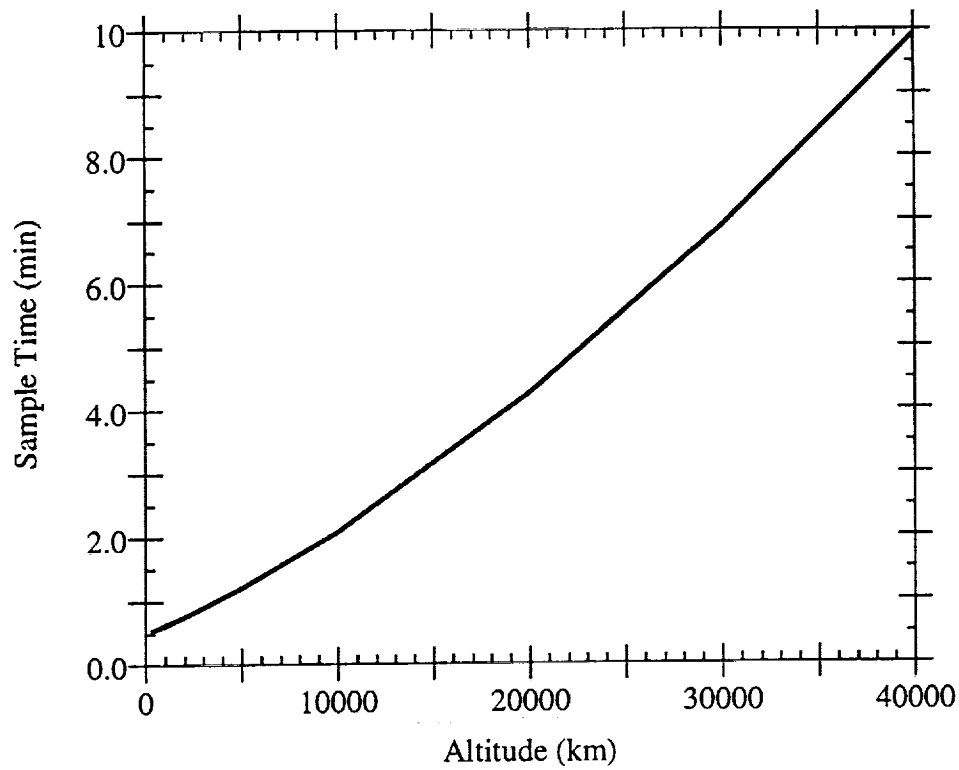

Fig. 9. General guide for setting sample time input values for circular orbits at different altitudes.

Input Value Selections for TRAP/SEE

Two factors should be considered in specifying TRAP/SEE input values for the number of orbits to be calculated and the sampling time:

First, the TRAP/SEE code runs relatively fast, so liberal value choices that ensure flux convergence for LEO orbits can be specified. For example, for a LEO 500 km circular orbit, one minute sample time, and 100 orbit run time, the calculation takes less that 30s on a Pentium II PC with 300 MHz clock speed. HEO orbits take longer, but still reasonable, times. For example, for the 10,000 km x 140,000 km HEO orbit considered earlier and performing the calculation for a 5-yr mission (683 orbits) and 20 min sample time takes about four minutes computation time.

Second, the adequacy of the TRAP/SEE input values for achieving flux convergence for LEO orbits can be readily verified. This can be done by selecting the point-by-point output option. The last column of this output contains "running average" flux values (default energy threshold values: protons > 100 MeV for an AP8 calculation, electrons > 1 MeV for an AE8 calculation) at each time step during the orbit calculation where non-zero fluxes occur. These running average values can be scanned for increasing time steps to check the flux convergence.

5.3 Magnetic Field Models

The AP8 and AE8 model data bases consist of integral flux values stored as a function of E, B/B_o, and L, where E is the particle energy, B is the magnetic field intensity, $B_o = M_o/L^3$ is (approximately) the minimum magnetic field intensity where the field line crosses the magnetic equator, M_o is the magnetic moment, and the McIlwain L parameter is a measure of the radial extent of the field line. Thus, to retrieve flux values from the data bases, a magnetic field model (consisting of coefficients for spherical harmonic expansion terms that describe the field), it is required that B, B_o, and L be calculated at each time step during the orbit calculation. It is essential that the magnetic field models used in retrieving the flux data correspond to the fields for the epoch the data bases were generated – the use of present day magnetic fields can give completely erroneous results [25].

Magnetic field models commonly used in conjunction with the AP8 and AE8 models (and which are the ones used in the TRAP/SEE code) are: the 80-term International Geomagnetic Reference Field for 1965.0 [7] projected to 1964 for solar minimum calculations and the U.S. Coast and Geodetic survey 168-term geomagnetic field model for 1970 [8] for solar maximum calculations.

While the above models define the magnetic fields at the times the trapped model data bases were generated, recent investigations by Heynderickx, et al. [26] indicate that the magnetic field models actually used in analyzing the majority of the flight data for incorporation into trapped model data bases were an interim 48-term model by Jensen and Cain [27] extrapolated to epoch 1960 for AP8MIN, AE8MIN, and AE8MAX and a GSFC 12/66 model by Cain, et al. [28] extrapolated to 1970 for AP8MAX. Heynderickx, et al. [26] argue that for complete consistency these magnetic field models should be used in extracting flux values from the trapped model data bases, and these field models are used in the European Space Agency UNIRAD trapped radiation environment and effects code system [29].

Thus, different magnetic field model choices based on reasonable assumptions have been used, although it is clear that the field model used <u>must</u> represent the epoch of the data collection. A comprehensive investigation of the sensitivity of trapped spectra model predictions to magnetic field model choices has not, to our knowledge, been performed.

5.4 Magnetic Moment

As indicated in Sec. 5.3, the dipole moment M_o of the geomagnetic field must be specified to retrieve fluxes from the AP8 and AE8 data bases. As originally issued, the AP8 and AE8 models used a fixed value for the magnetic moment, $M_o = 0.311653$ gauss R_E^3, corresponding to the magnetic field of 1960.

In the TRAP/SEE code an alternate procedure is used where M_o is calculated from the field model expansion coefficients for the epoch of the field (1964 for solar minimum and 1970 for solar maximum). This procedure of using a calculated rather than fixed M_o value is currently used in trapped radiation code predictions at MSFC and JSC, for example. While we are not aware of any systematic investigations of the effects of fixed vs. calculated moment values on predicted fluxes, for the LDEF satellite orbit (28.5°, 319-479 km altitude), the use of a calculated rather than fixed moment value gave reduced proton fluxes by about 5% at the highest altitudes and a factor of two at the lowest altitudes [30].

5.5 Data Base Interpolation

A shortcoming of the AP8 model is that the flux data base grid is coarse at low altitudes where protons are being removed by atmospheric interactions and the flux vs. altitude gradient is very steep. Daly and Evans [4] of the European Space Agency (ESA) have devised an improved data base interpolation method for such low altitudes. They define a new variable for interpolation purposes, $\phi = \sin^{-1} [(B - B_o)/(B_{max} - B_o)]$, where B_{max} is the field strength at the atmospheric cutoff. Then ϕ and L are used for flux data interpolation rather than B/B_o and L. For altitudes below about 500 km, the ESA interpolation method gives proton fluxes about 20 – 40% higher (depending on altitude, proton energy, and solar cycle conditions) than the standard interpolation method, with little difference at higher altitudes [4].

For the TRAP/SEE code, the user is given the option of using either the standard interpolation method (referred to here as "Vette method") or the Daly and Evans interpolation method (referred to here as "ESA method"). The ESA interpolation method can be used for either electron or proton predictions, but the results for electrons are not appreciably different using the two interpolation methods. Extensive proton and electron flux spectra comparisons using the Vette and ESA methods are given in [6].

6. References

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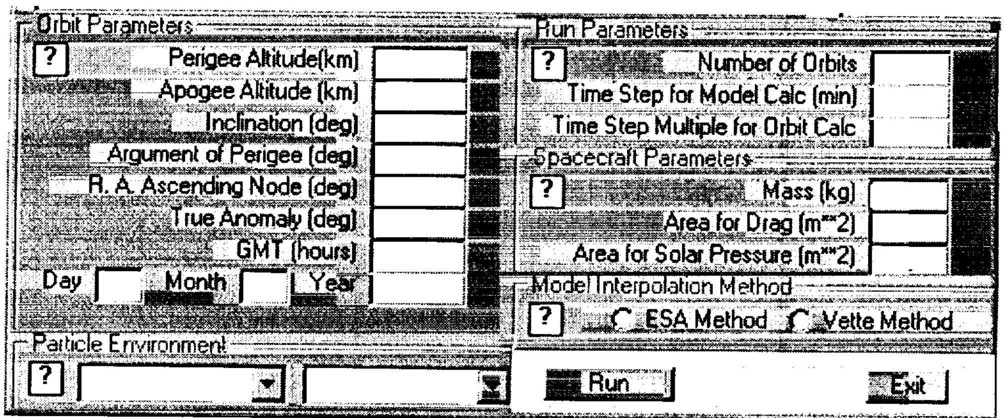
Appendix A

Input Description

Input parameters that need to be set to run the TRAP/SEE code are described below; descriptions are also included as Help files in the code, accessible by clicking on the "?" symbols on the user interface screens. The input parameters which need to be specified are shown on the interface screen below. (An alternate mode of code operation where spectra are calculated at a specified (B,L) point on an orbit is described later in Appendix D.)



A.1 Orbit Parameters

A brief description of input orbit parameters is given below; detailed definitions of orbit parameters are available in numerous publications – e.g., ref. [24] given in the text (Sec. 6).

NOTE: For circular orbits, calculations can be made by setting values only for perigee, apogee (= perigee), and inclination, with all other orbit parameters (optionally) set to 0.

⑨ Perigee Altitude: distance from Earth's surface to point on orbit having smallest height above the Earth's surface.

⑨ Apogee Altitude: distance from Earth's surface to point on orbit having largest height above the Earth's surface.

⑨ Inclination: angle between satellite's orbit plane and Earth's equatorial plane (plane containing Earth's equator).

⑨ Argument of Perigee: angle (with apex at center of Earth) from ascending node to perigee, measured in direction of satellite passage. (The ascending node is where the satellite crosses the equatorial plane from south to north.)

⑨ R. A. Ascending Node: right ascension of the ascending node is the angle in the equatorial plane measured eastward from the vernal equinox to the ascending node.

⑨ True Anomaly: true anomaly specifies where the satellite is located in its orbit, and is the angle (with apex at the center of the Earth) between the perigee point and the satellite location, measured from the perigee point.

⑨ GMT: Greenwich meridian time (in hours) for start of orbit calculation. Input as a decimal number.

⑨ Day, Month, Year: starting date for orbit calculations

NOTE: These dates are used only in the orbit calculation; they have no relevance to the time variation of the trapped radiation environment. (The trapped models are only applicable for times at or near solar maximum or solar minimum.)

A.2 Particle Environment

The choices here are trapped proton or trapped electron environments at either solar minimum or solar maximum.

NOTE: In trying to match solar minimum or solar maximum model outputs to represent the time frame of a particular mission, note that the most recent solar maximum occurred about 1991.0, and the most recent solar minimum occurred about 1996.5. The times of the other minima and maxima can be estimated by displacing these values by 11 years, corresponding to the approximate duration of the solar cycle.

A.3 Run Parameters

⑨ Number of Orbits: calculation is carried out for the number of orbits entered here.

NOTE: To perform the calculation for a specified mission time T, the equivalent number of orbits, N, needed for input is N = T/P, where P, the orbit period, is: P(minutes) = (1.6587e-4) * [A^(3/2)] and A is the semi-major axis in km. For circular orbits: A = H + RE, where H is the altitude and RE = 6378.14 km is the Earth's equatorial radius. For elliptical orbits, A=(HP + HA + 2RE)/2, where HP is perigee altitude and HA is apogee altitude.

⑨ Time Step for Model Calculation: this specifies the time steps during the orbit calculation at which trapped radiation fluxes are calculated.

NOTE: The combination of number of orbits and model time steps needed to adequately sample the radiation belt to obtain orbit-average flux spectra depends on the orbit of interest. Guidelines for setting these parameters are discussed in Sec. 5.2.

The point-by-point output file contains (as last column) the cumulative orbit-average flux after each time step. These results can be viewed to check convergence.

⑨ Time Step Multiple for Orbit Calculation: time steps for the orbit calculation (in seconds) is determined by : T0 = T * 60/M, where T is the model time step (in minutes, from above input) and M is the factor input here. This flexibility of different time steps for flux sampling and orbit element updates is advantageous for highly elliptical orbit calculations. (Nominal input values are T=1, M=1 for LEO and T=20, M=5 for HEO.)

A.4 Spacecraft Parameters

- Mass (kg): spacecraft mass, used in atmospheric drag calculations. (Default value = 1.)

- Area for Drag (m**2): effective spacecraft area, used in atmospheric drag calculations. This effective area is the product of the drag coefficient (a dimensionless number, typically between 1 and 2, with a value of 2 representative of large spacecraft), and the physical cross sectional area of the spacecraft perpendicular to the velocity vector. (Default value = 0.)

- Area for Solar Pressure (m**2): cross sectional area of the spacecraft perpendicular to sunline, used in calculating orbit perturbation caused by the solar radiation pressure. (Default value = 0.)

A.5 Model Interpolation Method

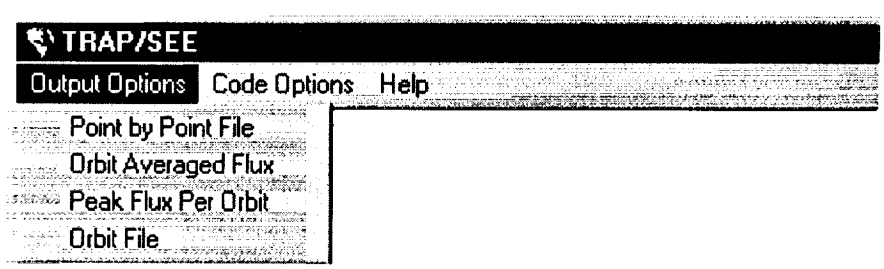
- ESA Method: uses an improved numerical interpolation method, developed by Daly and Evans at the European Space Agency/ESTEC facility, to extract flux values from the model data bases.

- Vette Method: uses original interpolation method of Vette, et al. to extract flux values from model data base.

  NOTE: See Sec. 5.5, and references therein, for discussion of these two methods. The two methods give significantly different results only for protons at low altitudes (below about 500 km).

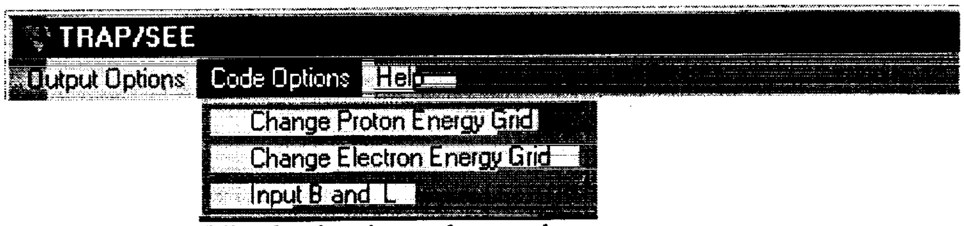
A.6 Output Option Selections

The default output is a table of orbit-average integral and differential flux energy spectra. To obtain output files containing point-by-point output, peak flux values, and an orbit-parameter file (described in Appendix B), these options must be selected at start of run under the "Output Options" pull-down menu on the user interface screen (partial screen shown below).



A.7 Code Option Selections

Under the "Code Options" pull down menu (partial screen shown below), the default energy values used for (a) energy spectra energy grid, (b) threshold energies for peak flux output, and (c) threshold energies for the point-by-point output may be changed, as discussed in Appendix C.



If the "Input B and L" selection is made, another screen appears enabling differential and integral flux spectra to be calculated at the point in space specified by input B and L values. This operational mode option, which is illustrated in Appendix E, allows the full energy spectrum to be obtained at any time step along the orbit using B and L values from the point-by-point (or peak flux) output files.

Appendix B
Output Description

B.1 Output Provided

Orbit Average Flux Spectra

The default output option provides orbit-average integral and differential flux spectra. For proton spectra the energy grid consists of 20 energy values from 0.05 - 600 MeV; for electron spectra, 20 energy values from 0.04 - 7.5 MeV are used. The default energy grid, and procedure for changing, is given in Appendix C.

Peak Flux

If the "Peak Flux per Orbit" option under the pull-down "Output Options" menu is selected, a table of peak flux values corresponding to the maximum integral flux (default threshold energies: > 1 MeV for protons, > 0.04 MeV for electrons) encountered over all time steps for a given orbit is generated. Also included in this output table is:

(a) the orbit number, and the location (longitude, latitude, altitude), elapsed time, the magnetic field intensity B, and the McIlwain L parameter (in Earth radius units) corresponding to the time step at which the peak flux occurred,

(b) the cumulative integral fluence for the whole orbit (default threshold energies: protons > 1 MeV, or electrons > 0.04 MeV), and

(c) the longitude of the south-to-north equatorial crossing for the orbit.

The maximum number of output lines in the table is set to 500 orbits. No output is provided for orbits having zero flux.

Point-by-Point Output

If the "Point-by-Point File" option is selected under the pull-down "Output Options" menu, a file containing variables at each time step during the calculation is generated. (Variables are printed only if the flux value for at least one of the threshold energies at the time step is nonzero.)

The output contains values at each time step for:

(a) the orbit position in terms of longitude, latitude, and altitude,

(b) B and L values,

(c) elapsed orbit time from start of calculation,

(d) integral flux values at the time step above three threshold energies; the default threshold energies are 1, 10, and 100 MeV for protons, and 0.04, 1.0, and 3.0 MeV for electrons, and

(e) the "running average" integral flux (default threshold energies: > 100 MeV for protons, > 1 MeV for electrons) -- i.e., the cumulative integral flux from the start of the orbit calculation divided by the elapsed time from the start of the calculation.

Orbit File

The orbit file contains values for selected orbit parameters at each time step of the orbit trajectory calculation. This output is for each time step, not just at nonzero flux time steps as for the point-by-point output. The output consists of the following variables (which are unlabeled in file) at each time step: longitude (deg), latitude (deg), altitude (km), B (gauss), L (Earth radii units), and elapsed time (hrs). This output option is useful only in special cases and is usually not selected.

B and L File

This optional output file contains differential and integral spectra at specified (B, L) points. It is generate only if the "B and L" option is selected and exercised under the "Code Options" menu.

B.2 Output Files

Table B-1 summarizes the output files generated and naming convention. For the B and L file, spectral results for multiple (B, L) points calculated during a session are appended in the same file.

Output files are automatically named using a string of abbreviations for key input parameters. An initial sequential "Index" (1, 2, . . .) denotes the number of different calculations made during a session. The index in the file name is followed by the "Run Identifier" information, consisting of: perigee altitude, apogee altitude, inclination, "P" or "E", denoting proton or electron model, "Max" or "Min", denoting solar maximum or solar minimum, "VET" or "ESA", denoting Vette or ESA interpolation method, and xOrb, where "x" is the number of orbits run. "BandL" is a default file name for the spectra at (B, L) points; the assigned file name can be changed by the user on the B and L calculation screen.

Table B-1. Output files generated.

Content	Selection	File Name and Extension (a)
- Orbit Average File: Orbit-average differential and integral flux spectra	default	(Index)(Run Identifier).txt
- Peak Flux File: Peak flux per orbit and fluence per orbit	Optional - select under "Output Options" menu	appended to Orbit Average File
- Point-by-Point File: Variables at each non-zero flux point along orbit	Optional - select under "Output Options" menu	(Index)(Run Identifier) .doc
- Orbit File Selected variables at each time step along orbit	Optional - select under "Output Options" menu	orbit.txt
- B and L File: Differential and integral spectra at specified (B,L) points	Optional - select under "Code Options" menu	BandL.txt

(a) See text for (Index) and (Run Identifier) definitions

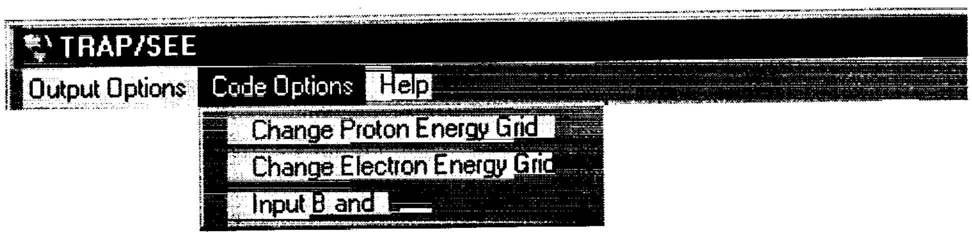
The output file sizes are relatively small except for the orbit file. For example, for the LEO example calculation described in Appendix D, the default orbit average and peak flux file is 10 kilobytes (kb), the point-by-point file is 92 kb, and the orbit file (seldom selected) is 510 kb. For HEO cases where typically calculations are made for a much larger number of orbits, the file sizes are larger but not unreasonably large.

Appendix C
Changing Default Energy Values

Default energy values may be changed for:

- energy grids used for calculating spectra,
- energy threshold values used in calculating peak fluxes, and
- energy threshold values used in calculating point-by-point fluxes.

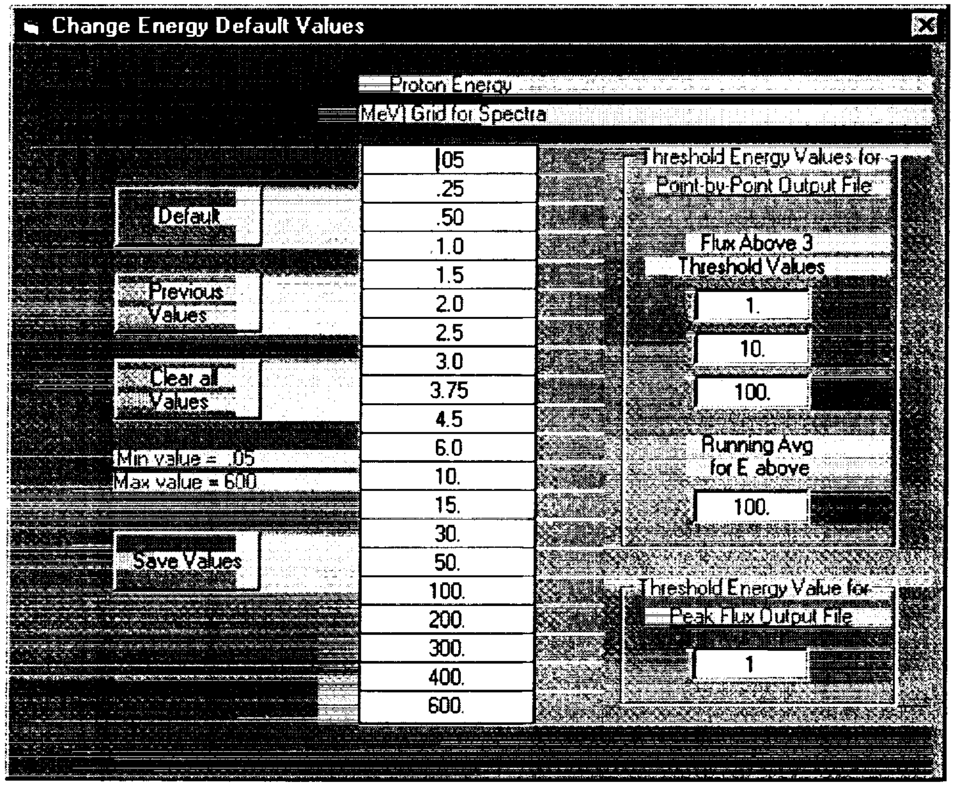
To view or change the default values used, select either "Change Proton Energy Grid" or "Change Electron Energy Grid" under the Code Options menu (shown below).

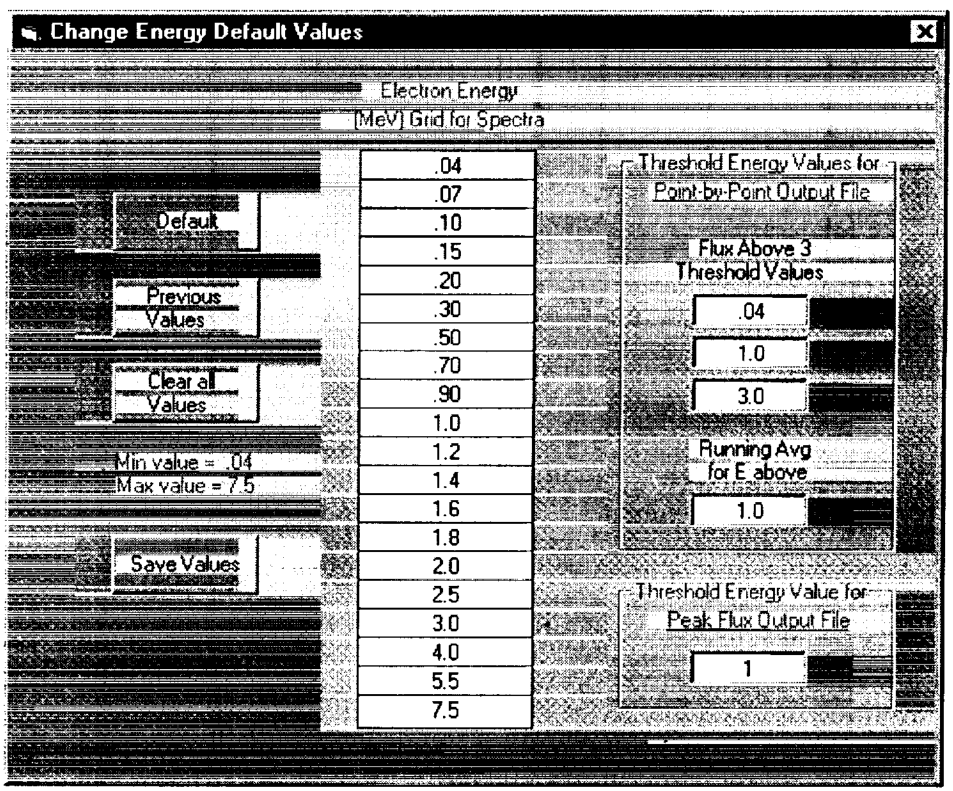


After this selection, a screen for changing either the proton or electron values (reproduced on next page) appears. Restrictions for user defined energies are:

- The energy grid values for spectra must be within the energy limits indicated on the screens.
- The number of energy grid values cannot exceed the default value of 20.
- Fewer than 20 energy grid values may be used, but should not be less than 5.
- The threshold energy values used for the point-by-point and peak flux output should correspond to one of the energy grid values used for the spectra calculation.
- The threshold energy specified for calculating the running average flux should correspond to one of the three threshold energies used for the point-by-point flux output.

For the point-by-point or peak flux energies to appear on the screen for changing default energies, these files must have been selected as output options under the "Output Options" menu.

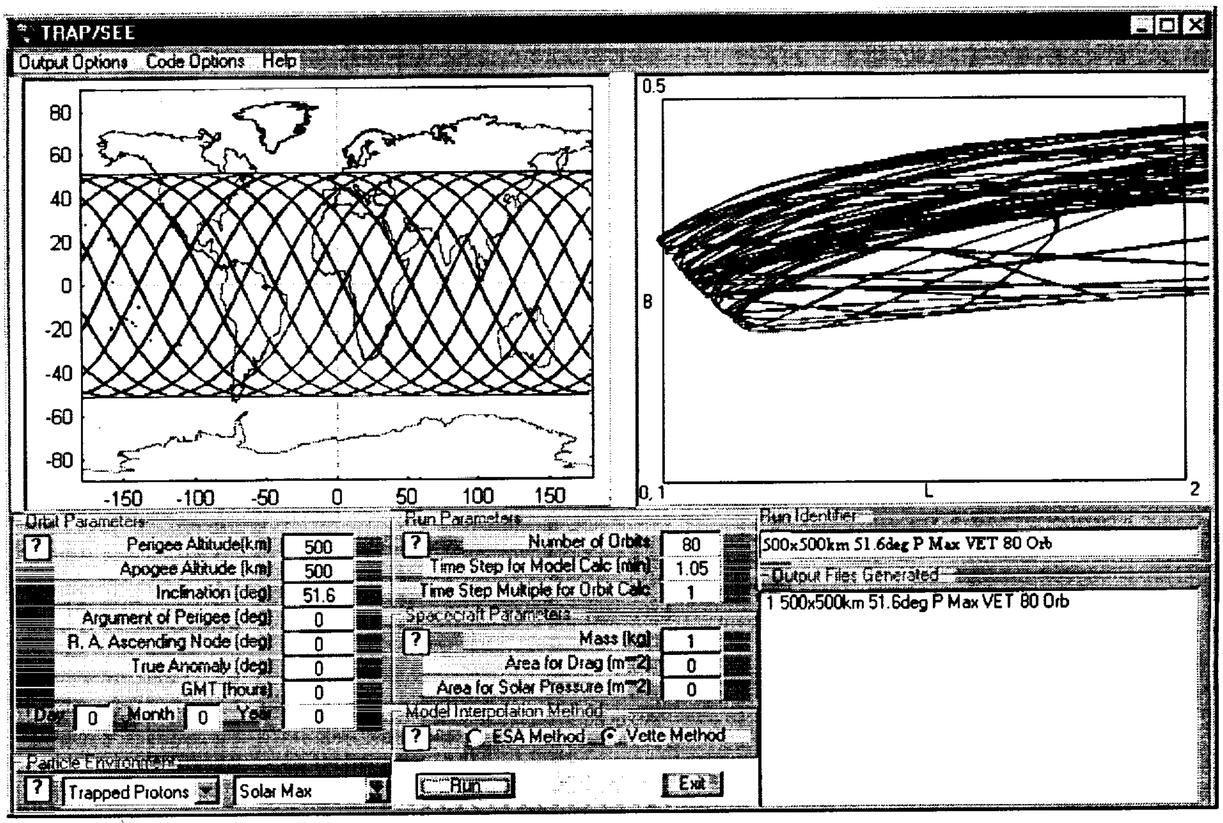

Change Energy Default Values
Proton Energy
MeV) Grid for Spectra
Default
Previous Values
Clear all Values
Min value = .05
Max value = 600
Save Values
.05
.25
.50
1.0
1.5
2.0
2.5
3.0
3.75
4.5
6.0
10.
15.
30.
50.
100.
200.
300.
400.
600.
Threshold Energy Values for Point-by-Point Output File
Flux Above 3 Threshold Values
1.
10.
100.
Running Avg for E above
100.
Threshold Energy Value for Peak Flux Output File
1


Change Energy Default Values
Electron Energy
MeV) Grid for Spectra
Default
Previous Values
Clear all Values
Min value = .04
Max value = 7.5
Save Values
.04
.07
.10
.15
.20
.30
.50
.70
.90
1.0
1.2
1.4
1.6
1.8
2.0
2.5
3.0
4.0
5.5
7.5
Threshold Energy Values for Point-by-Point Output File
Flux Above 3 Threshold Values
.04
1.0
3.0
Running Avg for E above
1.0
Threshold Energy Value for Peak Flux Output File
1

Appendix D
Example Calculation

D.1 Input Parameters

Input parameter settings for an example calculation are shown on the user interface screen below. Options to obtain peak flux and point-by-point values as output have been selected under the Output Options menu.



D.2 Screen Graphics

The left graphics screen shows a ground trace plot of the projected orbit in geographical latitude-longitude coordinates as the orbit calculation is performed. (Points on the orbit having nonzero flux values are connected with a red-colored line.)

The right screen shows the orbit plotted in B and L coordinates, where B is the magnetic field strength (in gauss) and L, the McIlwain L parameter, is a measure of the field line radial distance. If the orbit apogee altitude is < 1.5 Earth radii (= 9567 km), the scale limits are $B_{min} = 0$ to $B_{max} = 0.5$ and $L_{min} = 1$ to $L_{max} = 2$; if the apogee altitude is > 1.5 Earth radii, the upper scale limits are changed to $B_{max} = 0.2$ and $L_{max} = 6$.

D.3 Output

Tables D-1 through D-3 show the example calculation output for energy spectra, peak flux, and point-by-point results, respectively.

Table D-1. TRAP/SEE code output for example calculation – flux spectra.

```
   Fri Nov 26 14:08:40 1999   TRAP/SEE CODE VERSION 1.1 (Nov 99)
   RUN IDENTIFIER: 1 500x500km 51.6deg P Max VET 80 Orb
   MAGNETIC MOMENT   3.081666525188535E-001 GAUSS
Perigee Alt. (km):......     500.0          Apogee Alt. (km):.......     500.0
Inclination (deg):......      51.6          Perigee Arg. (deg):.....        .0
R.A. Ascend Node (deg):.        .0          True anomaly (deg):.....        .0
Mass (kg):.............1.0000E+00           Area for Drag (m^2):....0.0000E+00
Area for Solar Press:...0.0000E+00          No of Orbits:...........        80
T step Model Calc (min):     1.050          T Step Mult Orbit Calc:          1
day/mon/year........... 0/ 0/    0          GMT....................       .000
******************************************************************************
                        ORBIT AVERAGE FLUX TABLE

                  RUN IDENTIFIER: 1 500x500km 51.6deg P Max VET 80 Orb
                  MODEL USED = AP8 MAX
                  DATE FOR MAGNETIC FIELD MODEL =  1970
                  INTERPOLATION METHOD USED = Vette
                  TOTAL ORBIT TIME =     5.26 DAYS.
                  TIME STEP =    1.05 MIN.
                  ORBITAL PERIOD =   1.577 HRS.
```

E, ENERGY (MEV)	AVERAGE INTEGRAL FLUX ABOVE E (PER CM^2-DAY)	AVERAGE DIFFERENTIAL FLUX AT E (PER CM^2-MEV-DAY)
.05	5.74E+07	2.85E+08
.25	2.13E+07	8.99E+07
.50	8.66E+06	2.20E+07
1.00	3.54E+06	3.76E+06
1.50	2.58E+06	1.26E+06
2.00	2.14E+06	5.24E+05
2.50	1.98E+06	2.76E+05
3.00	1.86E+06	1.97E+05
3.75	1.73E+06	1.28E+05
4.50	1.66E+06	8.48E+04
6.00	1.55E+06	5.55E+04
10.00	1.38E+06	2.97E+04
15.00	1.28E+06	1.72E+04
30.00	1.08E+06	1.07E+04
50.00	9.07E+05	8.16E+03
100.00	5.66E+05	5.67E+03
200.00	1.95E+05	2.13E+03
300.00	6.40E+04	7.01E+02
400.00	2.18E+04	2.43E+02

600.00 2.50E+01

Table D-2. TRAP/SEE code output for example calculation – peak flux.

```
PEAK FLUX PER ORBIT TABLE

RUN IDENTIFIER:  1 500x500km 51.6deg P Max VET 80 Orb
MODELS USED = AP8 MAX
TOTAL TIME =     5.26 DAYS.
TIME INTERVAL =    1.05 MIN.
ORBITAL PERIOD =    1.577 HRS.
FLUX VALUES FOR ENERGY >    1.00
```

ORBIT NO.	PEAK FLUX (PART/CM^2-S)	LONGITUDE (DEG)	LATITUDE (DEG)	ALTITUDE (KM)	TIME (HRS)	FIELD(B) (GAUSS)	L VALUE (E.R.)	TOTAL FLUX/ORBIT (PARTICLES/CM^2)	S-N EQUATORIAL CROSSING (DEG)
5	5.005E+00	29.35	-31.19	495.1	7.24500	.25571	1.843	1.385E+03	196.02
6	7.136E+02	39.35	-48.76	503.0	8.96000	.29693	3.046	1.850E+05	172.19
7	3.384E+03	27.27	-50.87	504.4	10.57000	.28267	3.012	8.007E+05	148.37
8	3.188E+03	22.10	-51.36	505.7	12.19750	.27780	2.954	1.219E+06	124.55
9	9.309E+02	16.00	-48.64	506.0	13.82500	.26427	2.636	4.656E+05	100.72
10	6.713E+02	2.58	-45.27	505.6	15.43500	.24816	2.226	2.176E+05	76.90
11	4.213E+02	343.50	-43.14	505.3	17.02750	.23300	1.841	1.750E+05	53.08
12	1.330E+03	331.64	-35.93	504.0	18.65500	.21474	1.501	4.519E+05	29.25
13	8.427E+02	314.47	-30.39	502.9	20.26500	.20013	1.284	2.587E+05	5.43
14	9.980E+01	299.15	-21.53	501.3	21.89250	.20103	1.163	2.482E+04	341.61
20	4.375E+00	29.85	-31.41	495.2	30.85250	.25610	1.853	1.160E+03	196.45
21	4.316E+02	20.67	-41.64	499.3	32.49750	.25505	2.283	1.741E+05	172.62
22	2.443E+03	27.99	-50.92	504.2	34.17750	.28385	3.034	7.618E+05	148.80
23	3.444E+03	22.83	-51.32	505.4	35.80500	.27855	2.966	1.209E+06	124.98
24	9.599E+02	16.68	-48.53	505.5	37.43250	.26459	2.644	4.740E+05	101.15
25	6.753E+02	3.20	-45.12	505.1	39.04250	.24832	2.229	2.203E+05	77.33
26	4.158E+02	344.10	-42.97	504.8	40.63500	.23310	1.844	1.733E+05	53.51
27	1.327E+03	332.17	-35.72	503.4	42.26250	.21488	1.502	4.490E+05	29.69
28	8.207E+02	314.97	-30.16	502.4	43.87250	.20003	1.283	2.627E+05	5.86
29	1.036E+02	299.61	-21.29	500.8	45.50000	.20083	1.163	2.588E+04	339.82
35	3.969E+00	30.34	-31.63	495.4	54.46000	.25651	1.863	1.139E+03	196.88
36	4.711E+02	25.63	-43.93	500.3	56.12250	.26313	2.475	1.705E+05	173.05
37	1.739E+03	28.71	-50.97	504.0	57.78500	.28506	3.053	7.347E+05	149.23
38	3.703E+03	23.56	-51.29	505.1	59.41250	.27931	2.978	1.201E+06	125.41
39	9.262E+02	17.36	-48.42	505.1	61.04000	.26491	2.644	4.748E+05	101.58
40	6.734E+02	358.96	-46.76	504.9	62.63250	.24884	2.236	2.210E+05	77.76
41	4.220E+02	344.70	-42.80	504.3	64.24250	.23321	1.847	1.724E+05	53.94
42	1.303E+03	332.70	-35.51	502.9	65.87000	.21504	1.503	4.433E+05	30.12
43	8.549E+02	312.32	-32.68	502.3	67.46249	.20264	1.305	2.643E+05	4.07
44	1.039E+02	300.07	-21.05	500.3	69.10750	.20064	1.162	2.678E+04	340.25
50	4.077E+00	27.75	-29.07	494.7	78.05000	.25488	1.756	1.080E+03	197.31

(TRUNCATED)

Table D-3. TRAP/SEE code output for example calculation – point-by-point file.

```
Fri Nov 26 14:08:40 1999   TRAP/SEE CODE VERSION 1.1 (Nov 99)
RUN IDENTIFIER: 1 500x500km 51.6deg P Max VET 80 Orb
Vette method used.
****************************************************************************
POINT-BY-POINT (INTERMEDIATE) PRINTOUT (IF FLUX VALUE > 0)
RUN IDENTIFIER: 1 500x500km 51.6deg P Max VET 80 Orb
MODEL USED = AP8 MAX
```

LONGITUDE (DEG)	LATITUDE (DEG)	ALTITUDE (KM)	FIELD (B) (GAUSS)	L VALUE (E.R.)	ELAPSED TIME (HRS)	FLUX (PART/CM^2-S) ABOVE THRESHOLD ENERGIES (MEV) 1.	10.	100.	RUNNING AVG. FLUX (PART/CM^2-DAY) FOR E > 100.
26.31	-28.40	4.941E+02	.25421	1.728	7.22750	2.235E+00	1.966E+00	0.000E+00	0.000E+00
29.35	-31.19	4.951E+02	.25571	1.843	7.24500	5.005E+00	3.936E+00	0.000E+00	0.000E+00
32.59	-33.90	4.961E+02	.25923	1.970	7.26250	4.078E+00	1.905E+00	0.000E+00	0.000E+00
36.06	-36.50	4.972E+02	.26554	2.111	7.28000	4.261E+00	1.098E+00	0.000E+00	0.000E+00
39.78	-38.97	4.982E+02	.27512	2.276	7.29750	2.509E+00	0.000E+00	0.000E+00	0.000E+00
43.78	-41.30	4.992E+02	.28811	2.462	7.31500	1.160E+00	0.000E+00	0.000E+00	0.000E+00
52.71	-45.43	5.012E+02	.32304	2.929	7.35000	1.030E+00	0.000E+00	0.000E+00	0.000E+00
57.66	-47.17	5.021E+02	.34379	3.228	7.36750	1.702E+00	0.000E+00	0.000E+00	0.000E+00
356.92	-22.80	4.923E+02	.23301	1.440	8.76750	5.729E+00	4.503E+00	3.243E+00	5.593E+02
359.66	-25.73	4.932E+02	.23567	1.526	8.78500	5.194E+01	4.523E+01	2.576E+01	4.992E+03
2.54	-28.60	4.941E+02	.23815	1.622	8.80250	8.967E+01	7.630E+01	2.527E+01	9.323E+03
5.60	-31.39	4.951E+02	.24051	1.731	8.82000	1.027E+02	7.547E+01	1.149E+01	1.127E+04
8.85	-34.09	4.962E+02	.24293	1.851	8.83750	1.023E+02	6.379E+01	3.559E+00	1.186E+04
12.34	-36.68	4.972E+02	.24574	1.979	8.85500	1.347E+02	4.641E+01	1.751E+00	1.214E+04
16.08	-39.15	4.983E+02	.24938	2.119	8.87250	2.008E+02	3.282E+01	0.000E+00	1.211E+04
20.10	-41.46	4.993E+02	.25439	2.267	8.89000	4.016E+02	2.814E+01	0.000E+00	1.209E+04
24.42	-43.61	5.003E+02	.26131	2.440	8.90750	3.821E+02	6.953E+00	0.000E+00	1.206E+04
29.07	-45.56	5.013E+02	.27057	2.623	8.92500	2.902E+02	1.013E+00	0.000E+00	1.204E+04
34.05	-47.29	5.022E+02	.28244	2.831	8.94250	2.995E+02	0.000E+00	0.000E+00	1.202E+04
39.35	-48.76	5.030E+02	.29693	3.046	8.96000	7.136E+02	0.000E+00	0.000E+00	1.199E+04
44.96	-49.94	5.037E+02	.31379	3.288	8.97750	1.342E+02	0.000E+00	0.000E+00	1.197E+04
50.82	-50.82	5.044E+02	.33257	3.545	8.99500	2.445E+01	0.000E+00	0.000E+00	1.195E+04
56.87	-51.36	5.049E+02	.35263	3.818	9.01250	3.593E+00	0.000E+00	0.000E+00	1.192E+04
323.24	-10.85	4.897E+02	.20592	1.147	10.27250	9.270E+00	8.397E+00	2.046E+00	1.076E+04
325.59	-13.94	4.902E+02	.20382	1.167	10.29000	7.044E+01	6.522E+01	3.378E+01	1.571E+04
328.01	-17.01	4.908E+02	.20362	1.197	10.30750	1.612E+02	1.488E+02	1.106E+02	3.191E+04
330.52	-20.03	4.916E+02	.20500	1.239	10.32500	1.653E+02	1.476E+02	8.781E+01	4.471E+04
333.13	-23.02	4.924E+02	.20760	1.288	10.34250	3.289E+02	3.042E+02	1.842E+02	7.157E+04
335.87	-25.94	4.933E+02	.21108	1.350	10.36000	3.917E+02	3.497E+02	1.965E+02	1.001E+05
338.77	-28.80	4.942E+02	.21516	1.423	10.37750	6.325E+02	5.537E+02	2.661E+02	1.387E+05
341.84	-31.59	4.952E+02	.21962	1.508	10.39500	8.327E+02	7.177E+02	2.829E+02	1.796E+05

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Appendix E

Types of Applications

Both orbit-average and instantaneous trapped radiation flux spectra are generally needed for satellite radiation effects assessments. For example, orbit-average spectra are needed as input in determining mission dose vs. shielding and in assessing the lifetime performance degradation of certain components due to displacement damage. The default operational mode for the TRAP/SEE code provides such orbit-average spectra, and the number of orbits needed to obtain orbit averages representative of the whole mission has been discussed in Sec. 5.2.

Instantaneous flux spectra are needed in assessing radiation effects such as single-event effect rates in microelectronics, total dose rates, and background noise fluctuations produced in sensitive sensors by radiation. In addition to typical magnitudes for the instantaneous flux for the mission, the maximum mission fluxes are also usually needed so that "worse case" radiation effects analyses can be performed.

Instantaneous flux spectra can also be predicted using the TRAP/SEE code, where "instantaneous flux" means the flux average over the sampling time specified as input (nominally in the 1 to 10 min. range, as discussed in Sec. 5.2). The instantaneous flux spectra at orbit locations and times of interest can be obtained by: (a) using the peak flux per orbit (or point-by-point) output files that contain integral fluxes above specified energy thresholds to identify the location of interest, and the B and L values at this location, and then (b) calculating the integral and differential spectra over the full energy range at this B and L. Examples using this procedure are given below for LEO and HEO orbits.

The TRAP/SEE point-by-point output files contain various parameters (defined in Appendix B) which allow numerous types of analyses to be performed by the user. An example showing the altitude dependence of electrons and protons throughout the mission duration is given below. Such varied analyses are not automated but can be readily performed by importing the files into spreadsheets and graphics programs. For the analyses that follow, we have opened the output files using Microsoft WORD97©. (Some manipulation may be needed to format the point-by-point file results so that the values are aligned with the column heading descriptions. This can usually be done by choosing a font where each character corresponds to equal spacing, such as Monaco or Courier New, selecting landscape for the page orientation, and using a small , font size.) The text file can be imported into a spreadsheet (Microsoft EXCEL97© was used here), and the text-to-column command applied, so that various types of analyses can be performed, such as sorting by integral flux magnitude to identify maximum flux values and corresponding locations. For the results shown here, spreadsheet files were imported into the KaleidaGraph© graphics program for plotting.

E.1 Instantaneous Flux Spectra – LEO Example

A procedure for estimating the maximum differential and integral proton spectra over an LEO mission is illustrated here. The orbit considered is 500 km x 500 km with 51.6° inclination and 1.05 min. sample time, the same as for the example calculation in Appendix D. Figure E-1 shows a plot of the peak flux (> 50 MeV) per orbit file for the first 500 orbits. Also plotted for comparison is the average flux per orbit, obtained by dividing the fluence per orbit results in the peak flux file by the orbit period (1.577 hrs).

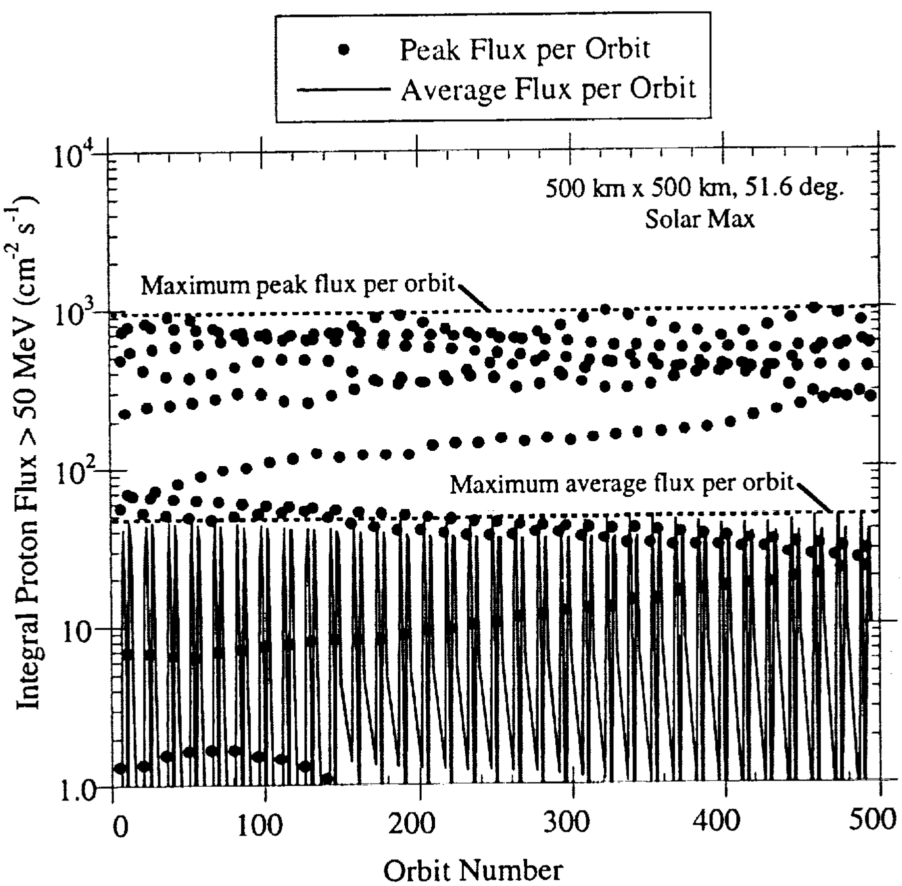
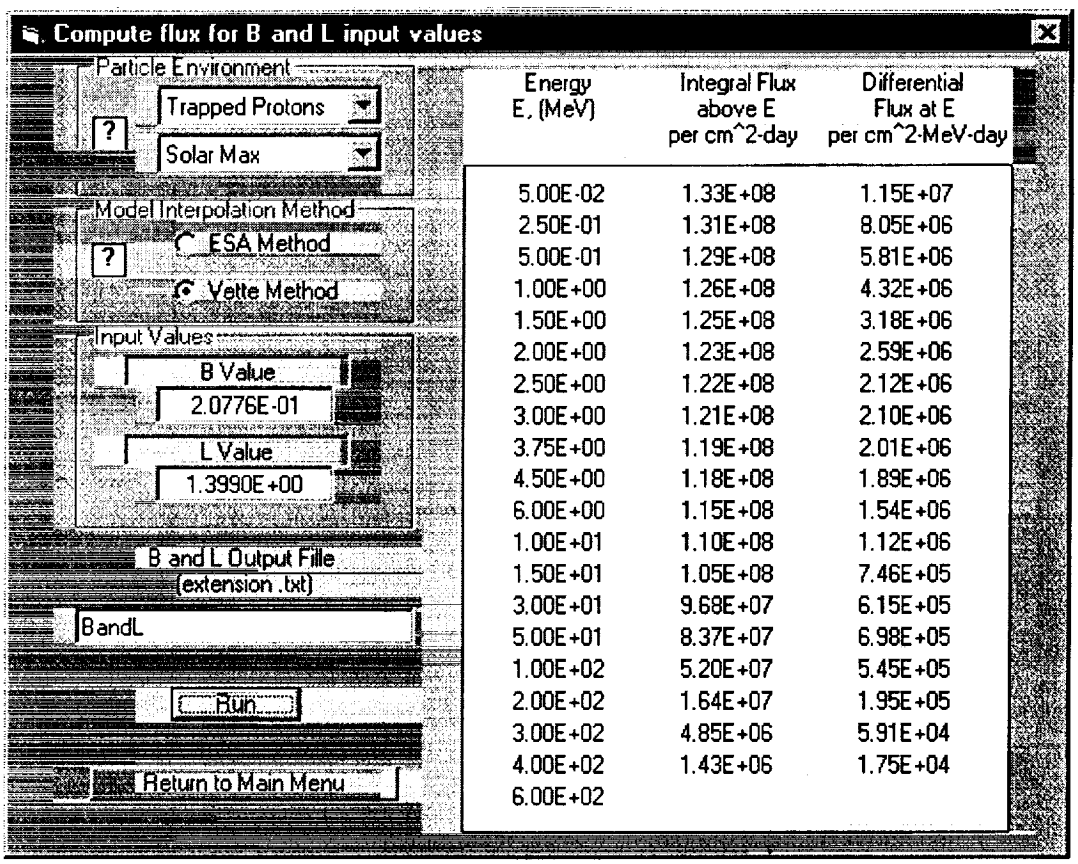


Fig. E-1. Peak and average proton flux per orbit for example LEO mission.

Figure E-1 shows that the maximum peak integral flux (>50 MeV) per orbit is approximately 1000 p/cm^2-s, the maximum average flux per orbit is about 50, and that these maxima are reached on numerous orbits. The peak flux variation is large since at this altitude different orbits pass through widely varying intensities in the South Atlantic Anomaly. Importing the peak flux values into a spreadsheet and sorting the peak flux file variables by descending peak flux magnitude, the maximum peak flux is 96.5 p/cm^2-s and occurs on orbit number 458. At this maximum flux location, B = 0.20766 and L = 1.399. Selecting the "Input B and L" option under the Code Options menu and inputting manually these B and L values, the differential and integral flux spectra at this orbit location can be calculated (Fig. E-2). By importing the output file generated by the spectra calculations (named "BandL.txt") into a graphics program, a plot of the spectra is obtained (Fig. E-3). Thus, the peak flux output file results and this procedure can be used to identify mission maximum fluxes and corresponding spectra.



Energy E, (MeV)	Integral Flux above E per cm^2-day	Differential Flux at E per cm^2-MeV-day
5.00E-02	1.33E+08	1.15E+07
2.50E-01	1.31E+08	8.05E+06
5.00E-01	1.29E+08	5.81E+06
1.00E+00	1.26E+08	4.32E+06
1.50E+00	1.25E+08	3.18E+06
2.00E+00	1.23E+08	2.59E+06
2.50E+00	1.22E+08	2.12E+06
3.00E+00	1.21E+08	2.10E+06
3.75E+00	1.19E+08	2.01E+06
4.50E+00	1.18E+08	1.89E+06
6.00E+00	1.15E+08	1.54E+06
1.00E+01	1.10E+08	1.12E+06
1.50E+01	1.05E+08	7.46E+05
3.00E+01	9.68E+07	6.15E+05
5.00E+01	8.37E+07	6.98E+05
1.00E+02	5.20E+07	5.45E+05
2.00E+02	1.64E+07	1.95E+05
3.00E+02	4.85E+06	5.91E+04
4.00E+02	1.43E+06	1.75E+04
6.00E+02		

Fig. E-2. Calculation of spectra at location of maximum peak proton flux.

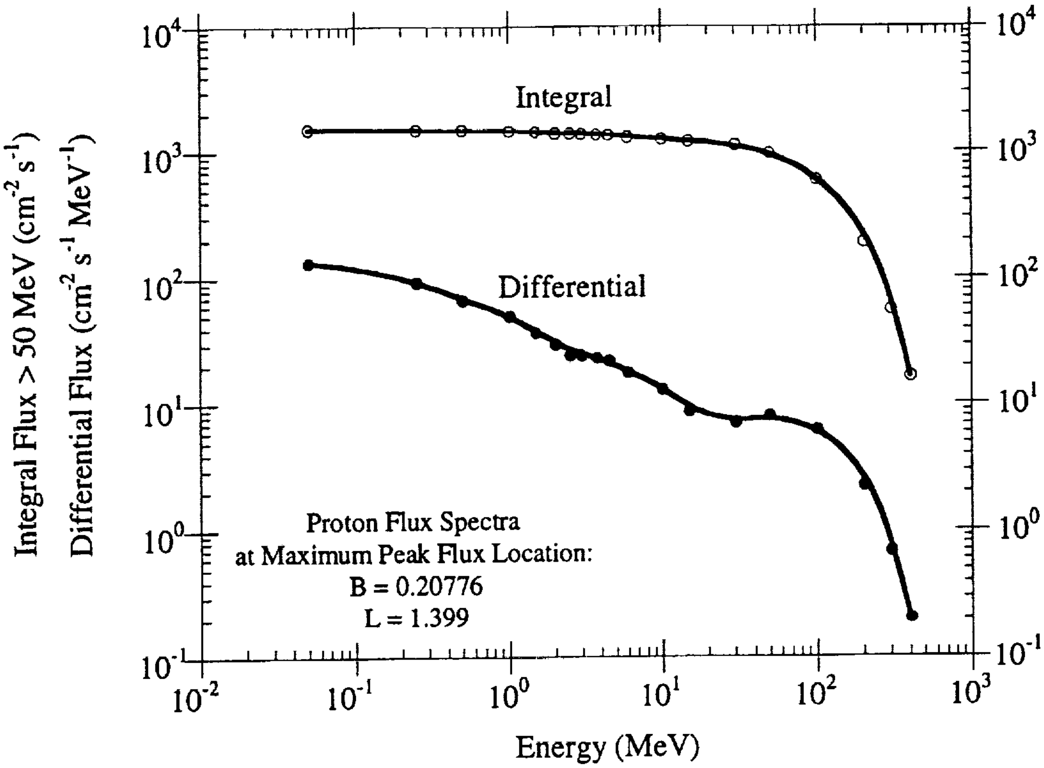


Fig. E-3. Plot of the proton spectra values in Fig. E-2.

E-2. Instantaneous Flux – HEO Example

Illustrated here are instantaneous proton and electron flux calculations for an HEO mission. The orbit parameters and TRAP/SEE input values used (for protons) are shown below. The calculation is made for the first two years of the mission.

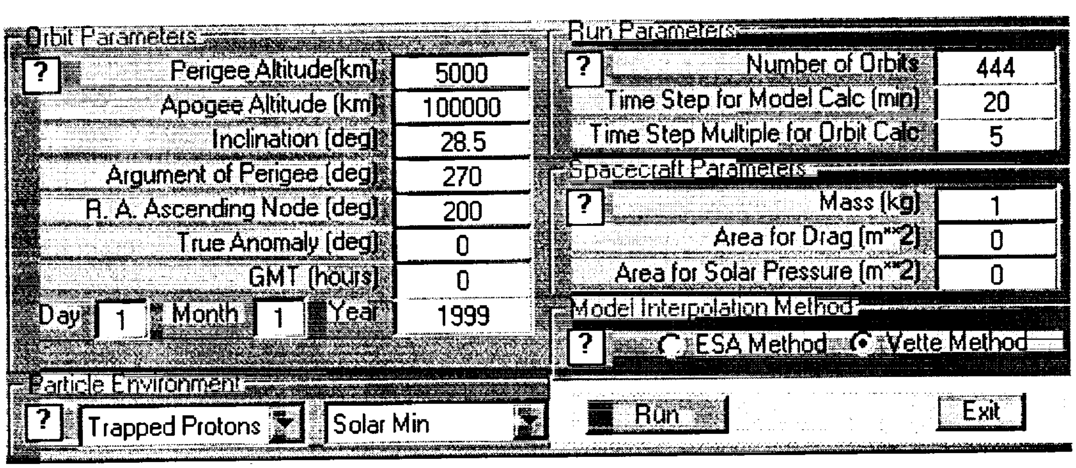


Fig. E-3. Plot of the proton spectra values in Fig. E-2.

Figure E-4 shows a plot of the instantaneous integral proton fluxes > 30 MeV and the cumulative average ("running average") integral flux from the point-by-point file for the first two years of the mission. The instantaneous flux corresponds to the flux average over the 20 min. sampling time specified as input. The flux in this case decreases with mission time since, as illustrated earlier (Sec. 5.1), perigee altitude increases with orbit time for such highly elliptical orbits due to perturbations of the orbit by nonspherical Earth gravitational terms and solar and lunar gravitational forces. Thus, orbit trajectories pass through less intense regions of the proton belt as mission time progresses. Since the increased perigee altitude is still below the outer electron belt, the cumulative and maximum instantaneous electron fluxes are essentially constant with elapsed mission time (Fig. E-5).

As illustrated above for the LEO orbit, the "Input B and L" option can be used to calculate the full differential and integral spectra at orbit locations or mission times of interest as identified by the integral instantaneous flux variations. Also, other variables in the point-by-point file can be used to help characterize the environment for particular missions and interests. For example, plotting the integral fluxes vs. altitude gives an overview of the altitude regions contributing to the flux, as illustrated in Fig. E-6.

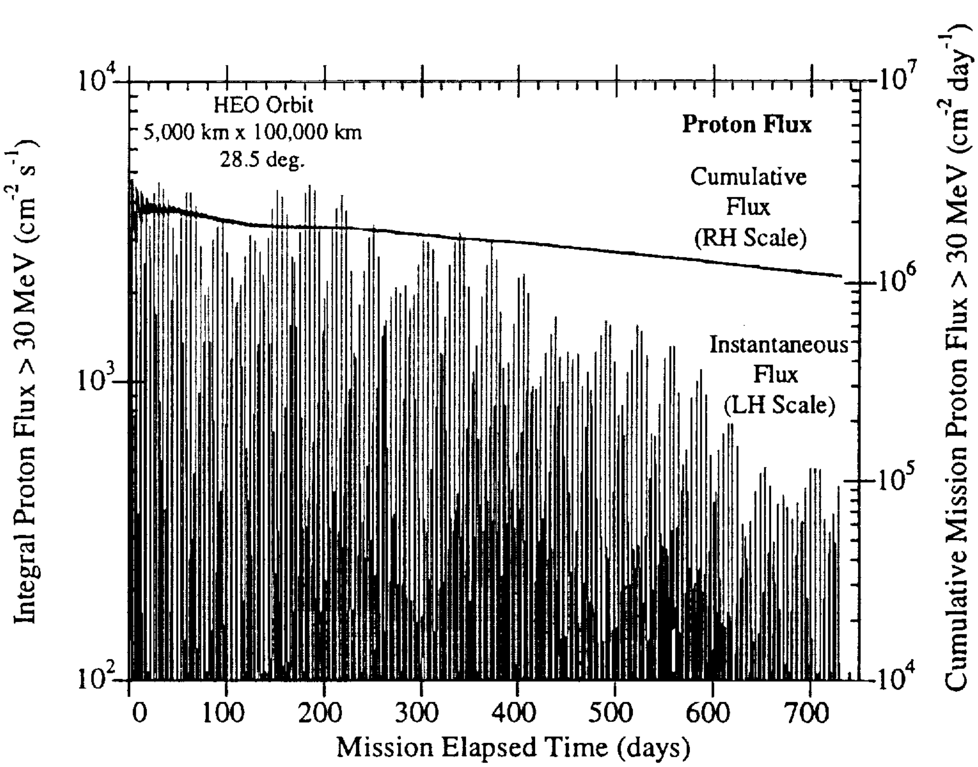


Fig. E-4. Instantaneous (20 min. average) and cumulative average proton fluxes for example HEO mission.

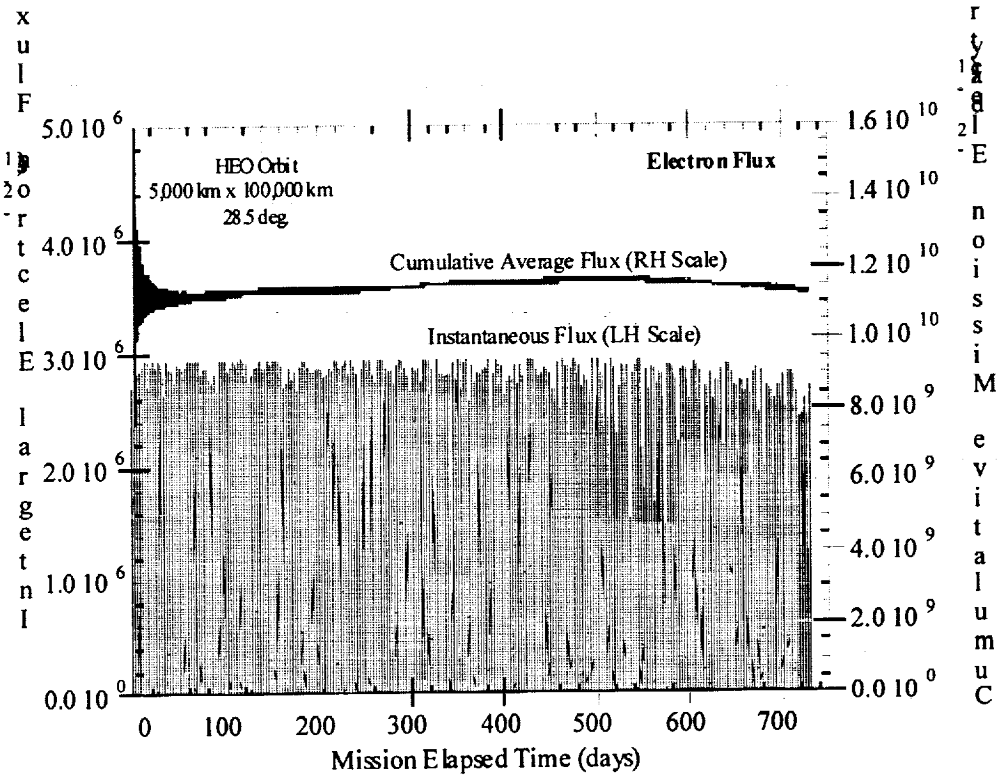


Fig. E-5. Instantaneous (20 min. average) and cumulative average electron fluxes for example HEO mission.

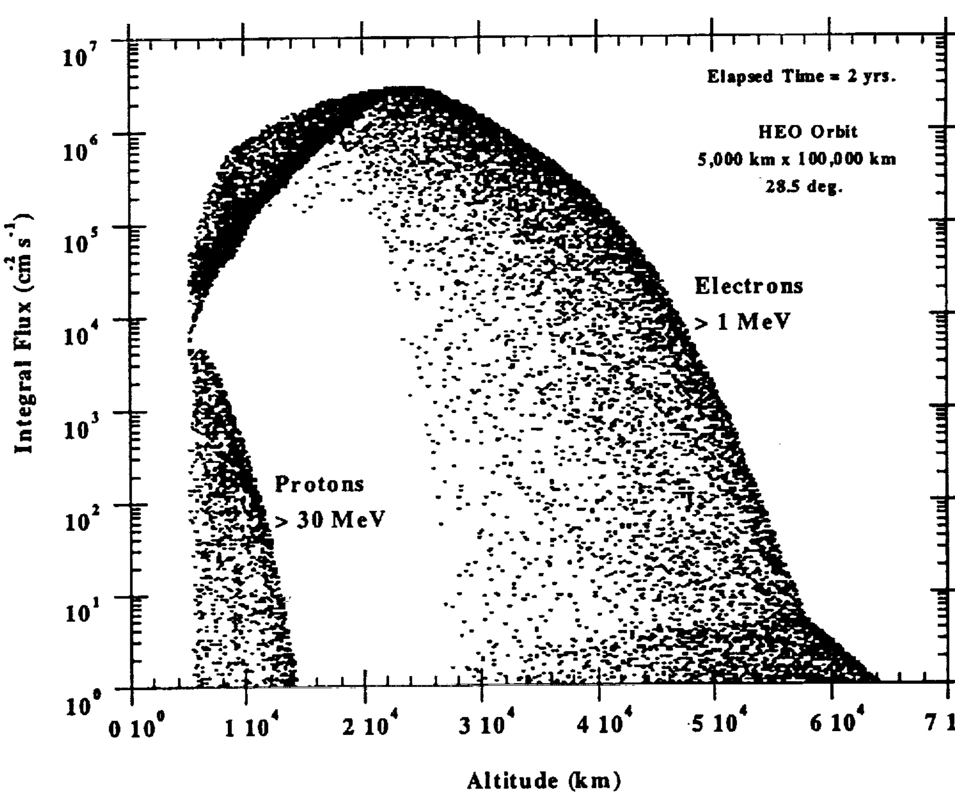


Fig. E-6. Altitude dependence of proton and electron fluxes for example HEO mission.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 2000	Contractor Report (Final)

4. TITLE AND SUBTITLE
TRAP/SEE Code Users Manual for Predicting Trapped Radiation Environments

5. FUNDING NUMBERS
Contract No. NAS8–40294

6. AUTHORS
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7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(ES)
Science Applications International Corporation (SAIC)
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Prospect, TN 38477

8. PERFORMING ORGANIZATION REPORT NUMBER
M–954

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA/CR—2000–209879

11. SUPPLEMENTARY NOTES
Prepared for NASA's Space Environments and Effects (SEE) Program
Technical Monitor: J.W. Watts, Jr.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Unlimited
Subject Category 93
Standard Distribution

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

TRAP/SEE is a PC-based computer code with a user-friendly interface which predicts the ionizing radiation exposure of spacecraft having orbits in the Earth's trapped radiation belts. The code incorporates the standard AP8 and AE8 trapped proton and electron models but also allows application of an improved database interpolation method developed by Daly and Evans. The code treats low-Earth as well as highly-elliptical Earth orbits, taking into account trajectory perturbations due to gravitational forces from the Moon and Sun, atmospheric drag, and solar radiation pressure. Orbit-average spectra, peak spectra per orbit, and instantaneous spectra at points along the orbit trajectory are calculated. Described in this report are the features, models, model limitations and uncertainties, input and output descriptions, and example calculations and applications for the TRAP/SEE code.

14. SUBJECT TERMS
trapped radiation models, trapped radiation code, space radiation software, space ionizing radiation environments

15. NUMBER OF PAGES
48

16. PRICE CODE
A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

National Aeronautics and
Space Administration
AD33
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama
35812